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ACOUSTICAL, PHYSICAL, AND BIOLOGICAL PROPERTIES OF SURFACE SEDI--ETC(U)
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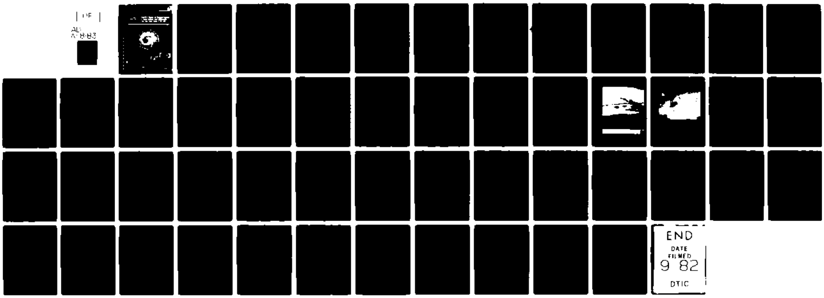

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Naval Ocean Research
and Development Activity
NSTL Station, Mississippi 39529


# Acoustical, Physical, and [illegible] of Surface Sediment Cores [illegible] Long Island Sound, August 27-28, [illegible]

NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY 1976

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## EXECUTIVE SUMMARY

Concurrent acoustical, physical, and biological properties were measured from three replicate core liner and three replicate box core samples collected by scuba divers from each of two locations in Long Island Sound 27-28 August 1980. Grain size distribution, porosity, and compressional wave velocity measurements were taken at 1 cm intervals in the core liner samples. Compressional wave velocities were measured at 0.5 cm intervals and porosity values at 1.0 cm intervals in the box core samples. X-radiographs were made of sediments collected with the box cores.

A very low diversity pioneering assemblage dominated by the filter-feeding bivalve *Mulinia lateralis* was found at the shallower (10 m water depth) FOAM site. Nearby sediments were dominated by pioneering, surface tube-dwelling polychaetes and amphipods. Sediment laminations produced by storm-induced erosional and depositional events were preserved at the FOAM site because sediment mixing by macrofauna was uncommon below the upper few centimeters of sediment. Horizontal patchiness of macrofauna and preservation of sediment laminations resulted in vertical and horizontal variability in sediment physical and acoustical properties. Spatial and temporal changes in dominant species at the FOAM site resulted in considerable large scale (10 to 100 meters) variability in surface physical and acoustical properties.

A low diversity equilibrium assemblage dominated by surface deposit-feeding bivalves and deeper dwelling errant and tube dwelling polychaetes was found at the deeper (16 m water depth) NWC site. Intense bioturbation by surface deposit-feeding bivalves precluded preservation of the primary laminations which had been created by storm-induced erosional and depositional events. Bioturbation was responsible for the spatial and temporal homogeneity of physical and acoustical properties at the NWC site. Deeper dwelling polychaetes mixed the sediment to depths of 15 cm, creating random variability of fine-scale physical and acoustical structure by production of burrows, tubes, and feeding voids, and by mixing shell remains throughout the upper 15 cm.

The physical and acoustical properties of coastal marine sediments are controlled by the interaction of biological and hydrodynamic processes. Study of the relationships between these two processes and the resultant sedimentary properties should lead to increased understanding and improved geoacoustic predictive models of coastal environments.

It is obvious from these data that caution must be exercised when sediment acoustic properties are predicted from sediment physical properties for shallow-water coastal sediments. Sampling designs which either define small-scale sediment property variability or make measurements over long pathlengths must be used to predict shallow-water sediment acoustic properties.

## ACKNOWLEDGEMENTS

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# ACOUSTIC, PHYSICAL, AND BIOLOGICAL PROPERTIES OF SURFACE SEDIMENT CORES COLLECTED FROM LONG ISLAND SOUND, AUGUST 27-28, 1980

## I. INTRODUCTION

Richardson and Young (1980) hypothesized that bioturbation by benthic animals alters acoustic properties of unconsolidated marine sediments. They based this hypothesis on known relationships between physical and acoustic properties of sediments (Hamilton, 1974), and the measured effects of bioturbation on sediment physical properties (Rhoads, 1974). Richardson and Young calculated that bioturbation by *Nucula annulata*, a deposit-feeding bivalve, would decrease the velocity and attenuation of compressional and shear waves in sediments while increasing bottom loss at the sediment-water interface. In this paper, we present the first field data collected to test this hypothesis. We further compare relative effects of hydrodynamic versus biological processes on acoustic and physical properties of sediments by intensively sampling two drastically different sedimentary environments in Long Island Sound. Special emphasis was placed on the effects of these processes on the spatial variability of sediment physical and acoustic properties.

## II. MATERIALS AND METHODS

### A. SITE SELECTION

Two locations in Long Island Sound were chosen for study. The Northwest Control (NWC) site is located in 16 m of water about 6 km south of New Haven Harbor. This location is dominated by deposit-feeding protobranch molluscs, *Nucula annulata* and *Yoldia limatula* and the errant polychaete, *Nephtys incisa* (McCall, 1977; Rhoads *et al.*, 1978; Yingst and Rhoads, 1978). The "Friends of Anoxic Mud" (FOAM) (Goldhaber *et al.*, 1977) site is located in 10 m of water near the Thimble Islands. Deposit-feeding bivalves are not common at the FOAM site; instead opportunistic pioneering species such as the bivalve *Mulinia lateralis*, the tube dwelling polychaetes *Streblospio benedicti*, *Capitella capitata*, *Owenia fusiformis*, and the tube dwelling amphipoda *Ampelisca abdita* (Rhoads and Boyer, in press) are dominant.

These locations were chosen for three reasons. First, the presence (NWC site) and absence (FOAM site) of a large population of *Nucula annulata* were required to field test our hypothesis (Richardson and Young, 1980). Second, sediment geotechnical properties at the NWC site are thought to be primarily biologically controlled while sediment geotechnical properties at the FOAM site are more influenced by storm action (Rhoads and Boyer, in press). Third, considerable research has been done on chemical fluxes (Goldhaber *et al.*, 1977; Aller, 1978a,b), radioisotope distribution (Aller and Cochran, 1976; Benninger *et al.*, 1979; Benoit *et al.*, 1979), sediment geotechnical properties (Rhoads, 1974; Bokuniewicz *et al.*, 1975), seafloor stability (Rhoads *et al.*, 1978; Yingst and Rhoads, 1978) and animal distributions (McCall, 1977, 1978; Rhoads *et al.*, 1977) at these sites.

### B. FIELD COLLECTION

Three replicate box core samples and three replicate cylindrical core samples each were collected with the aid of scuba divers, from both NWC and FOAM sites, August 27-28, 1980. The plexiglass box cores were 30 cm long, 20 cm wide and 30 cm high. The cylindrical cores were standard (5.8 cm inside diameter) piston core liners cut to 45 cm length and bevelled at one end to improve penetration into the sediment.

Both box cores and cylindrical cores were capped at both ends immediately after collection to retain water overlying the sediment. This method of collection results in minimal disturbance to the sediment-water interface (Rhoads et al., 1977).

After collection the box cores were transported to laboratory facilities at Yale University where acoustic probe measurements were made and subcores for porosity and for x-radiographs were collected. The cylindrical cores were packed in ice and transported to laboratories at NSTL Station where compression wave velocities were measured and the cores were sectioned for porosity and grain size analysis. Extreme care was exercised during transport of all cores so that the sediment-water interface would not be disturbed.

## C. LABORATORY ANALYSIS

The box core samples were equilibriated to room temperature for two hours before measurements were made. Temperature and salinity of the overlying water were measured with a YSI Model 43TD temperature probe and an AO Goldberg temperature-compensated, salinity refractometer.

At least two replicate series of compressional wave velocity measurements were made at 0.5 cm intervals in each box core. A block diagram of the acoustic measuring system is presented in Figure 1. A Tektronix PG 501 Pulse Generator was used to trigger a Tektronix FG504 Function Generator and a Hewlett Packard 1743A dual-time interval Oscilloscope (Fig. 1). The Tektronix FG504 Function Generator drove the compression wave transducer with a 70 kHz sine wave triggered for 10 μsec duration every 2 msec. The electric energy was transferred into mechanical energy using a piezoceramic thin sheet transducer (12.7 mm long, 2.5 mm wide and 0.25 mm thick) cut from a G1195 series thin sheet manufactured by Gulton Industries. The transducer was epoxied at one end into a 15 mm long, 10 mm wide window machined into a 2.4 mm thick Phenolic Sheet potted with Scotch Cast 8 (Fig. 2).

The compressional wave propagated through the medium being measured to two compressional wave receivers, built as identically as possible to the compressional wave transducer. The mechanical energy was transferred into electrical energy by the piezoceramic receivers, amplified (20 dB gain) by Burr-Brown 3622K Differential amplifiers; and filtered by Krohn-Hite Model 3100R Band-Pass Filters (1-1000 kHz high cut-off and low cut-off frequencies) set in the maximum flat butterworth position. The time delay ($\Delta t$) between the two, amplified, filtered, received signals was measured with the Hewlett-Packard Oscilloscope.

The first "$\Delta t$" measurement for each series was made in the water overlying the sediment-water interface. The difference in the distance between the transducer and the two receivers was calculated from the "$\Delta t$" measurement and the compressional wave velocity for sea water-given temperature, salinity, and depth (Wilson, 1962). It was assumed that the difference in distance between probes remained the same during any series of measurements. Time delay ($\Delta t$) measurements were made at 0.5 cm intervals as the probes were inserted into the sediment. Velocities of compressional waves at each depth were calculated from the difference in distance between the transducer and receivers and the measured time delay. The compression wave velocity values were corrected to a common temperature (20°C) and salinity (30°/oo) using Wilson's (1962) equations for speed of sound in sea water (after Hamilton, 1971).

After compressional wave velocities were measured, 30 cm long cylindrical cores (2.4 cm inside diameter) were inserted into each of the box core samples to collect

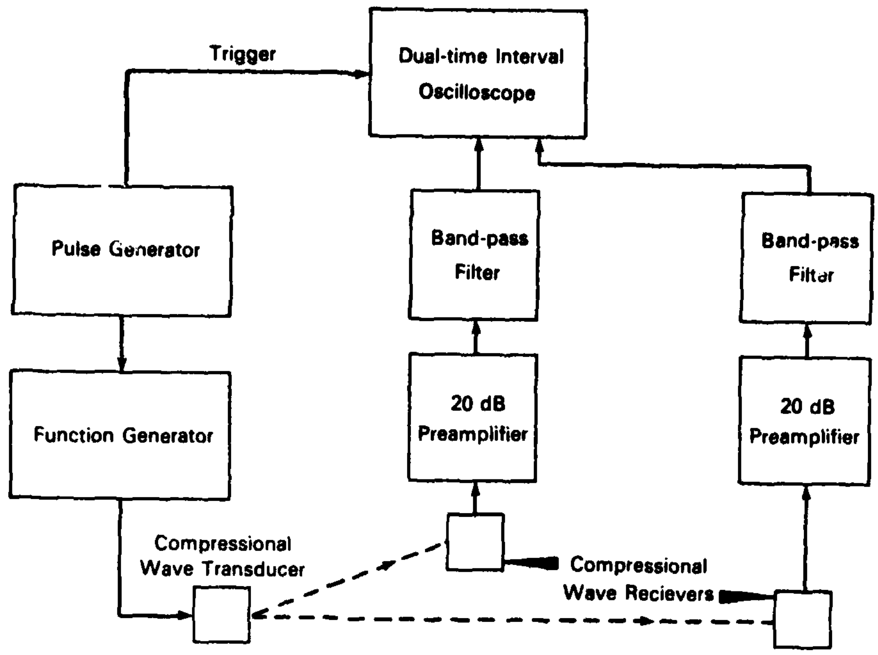



Figure 1. Block diagram of compressional wave velocity measuring system.

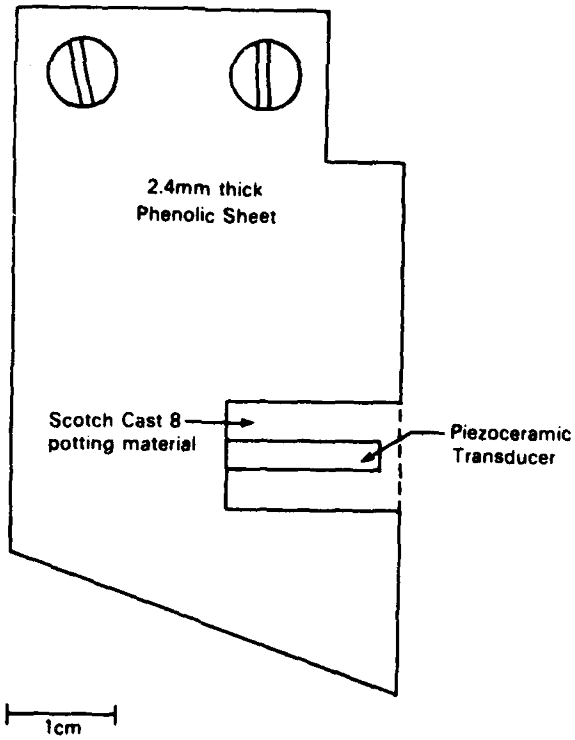



Figure 2. Line drawing of compressional wave velocity probes (transducer and receivers are identical).

sediment for porosity measurements. Plexiglass rectangular cores (25 cm high, 30 cm long and 2.5 cm wide) were then obtained from the first box core collected from both the FOAM and NWC sites for X-radiographic study of biological and sedimentary structures. These plexiglass cores were X-rayed by placing a 20.3 cm x 25.4 cm sheet of Kodak AA Industrial X-ray film on the back of the plexiglass core and exposing it to 60 kV for 30 seconds with a Kramex PX-20N portable X-ray unit (Rhoads et al., 1977). The X-radiographs were made by Dr. Donald C. Rhoads at Yale University.

The remaining sediment from each box core was rinsed through a 0.5 mm screen. The retained material was stained with rose bengal and preserved in 5% formalin buffered with $NaH_2BO_3$. Macrofauna were sorted from the preserved material and were identified and counted. Density values of macrofauna were corrected to account for small subcores taken from each box core. Macrofaunal diversity was calculated from the Shannon and Weaver (1963) information function (Pielou, 1966):

$$H' = - \; P_i \log_2 P_i ,$$

where $P_i$ is the proportion of individuals belonging to the ith species. Lloyd and Ghelardi (1964) have shown that diversity (H') values are sensitive to two components: the number of species in a sample (species richness) and the distribution of individuals among species (evenness). Species richness was estimated by

$$SR = (S - 1)/\ln N,$$

where S is the number of species and N is the number of individuals in a collection (Margalef, 1958). Evenness was computed (Pielou, 1966) as

$$J' = H'/\log_2 S.$$

Values of compressional wave velocity were determined for sediment in the cylindrical core liners with an Underwater Systems, Inc. (Model USI 103) Sediment Velocimeter. Time delay measurements made on distilled water through the core liner were compared to similar time delay measurements on the sediment sample to determine sediment compressional wave velocity using the following formula:

$$C_s = \frac{C_w}{1 - \frac{\Delta t C_w}{d}}$$

where $C_s$ is the measured sound velocity through sediment (m/sec); $C_w$ is the measured sound velocity through distilled water (m/sec); $\Delta t$ is the measured time arrival of sound through distilled water minus the time arrival through sediment (sec); and d is the inside diameter of the core in meters. All sound velocities were corrected to a common temperature and salinity (20°C, 30°/oo) after Hamilton (1971).

The porosity values were determined for sediment samples from the 2.4 and 5.8 cm diameter cores and grain size distribution was determined for sediment samples from the 5.8 cm diameter cores. Each small diameter core was sectioned at 1 cm intervals by extruding the sediment with a plunger and slicing the exposed sediment

off with a spatula. The large diameter cores were split lengthwise before sectioning at 1 cm intervals and then sampled with a spatula. Half of each large diameter core section was used for porosity determinations and the other half for grain size analyses.

Immediately after sectioning, the porosity samples were placed in preweighed aluminum pans, weighed, dried in an oven at 105°C for 24 hours, cooled in a desiccator, and reweighed. Percent water was calculated by dividing the weight of the evaporated water (difference between wet and dried sediment weights) by the weight of the dried solids and multiplying by 100. Using an average grain density value of 2.65, porosity values were determined from tables relating porosity to water content (Lambert and Bennett, 1972). The values were not corrected for the salinity of pore water.

The grain size analysis of sediment from the large cores was accomplished basically as described by Folk (1965). The silt and clay fractions (<62 μm) however, were determined with a Micromeritics[R] Model 5000 Particle Size Analy rather than the standard pipette method. The sediment samples were soaked overn t in 200 ml of dispersant solution (5 g sodium metaphosphate per liter of distil water), then disaggregated by sonicating the sample with a cell disruptor for minutes while stirring it with a magnetic stirrer. The disaggregated sample with ersant was wet-sieved through a 62 μm screen to separate the gravel-sand fracti m the silt-clay fraction. The finer fraction was collected in a 1000 ml gradu cylinder, and enough dispersant was added to fill the graduater cylinder to 1000 ml. The coarser fraction was rinsed off the screen into a beaker with distilled water and then dried.

The dried, coarser fraction was fractionated into -2, -1, 0, 1, 2, 3 and 4 phi ($\phi$) intervals ($\phi = -\log_2$ of grain size in mm) with an ATM Sonic Sifter and each fraction was individually weighed to determine the gravel and sand particle size distribution. The silt and clay size fraction was thoroughly agitated by vigorous stirring and aeration. A 20 ml aliquot sample representative of the total distribution of particles in suspension was pipetted from the graduated cylinder into a preweighed beaker, dried in an oven, and weighed. After all particles 10 $\phi$ and coarser settled to the bottom of the cylinder, the supernatant was slowly siphoned into another graduated cylinder, leaving the settled particles and about 200 ml of dispersant. The supernatant volume was recorded. A 20 ml aliquot was agitated, pipetted, dried in an oven, and weighed to obtain an estimation of the weight of the particles finer than 10 $\phi$. Finally, the sample remaining in the graduated cylinder was sonicated and stirred for 12 minutes in a beaker prior to size determination with the Micromeritics[R] analyzer. The Micromeritics[R] Particle Size Analyzer was used to determine the concentration of silt and clay-size particles in suspension at various depths in a sample cell by means of a finely collimated, horizontal X-ray beam. The concentration was presented in the form of a cumulative "percent-finer-than" distribution trace in relation to the Stokesian diameter of the particles.

Sediment grain size distributions were analyzed on a HP 9825A desktop computer and plotted with a HP 9862A plotter (unpublished program is available on request from MDR). Data were plotted as weight percent histogram and cumulative weight percent for all phi sizes through 14 $\phi$. The greater than 10 $\phi$ fraction was equally divided among the 11 through 14 $\phi$ fraction (Folk, 1965). Percentages of gravel (>-1.0 $\phi$), sand (-1.0 to 4.0 $\phi$), silt (4.0 to 8.0 $\phi$) and clay (<8 $\phi$) were calculated. The mean phi, standard deviation, skewness, kurtosis, and normalized kurtosis were calculated according to the graphic formula of Folk and Ward (1957).

## III. RESULTS

### A. MACROFAUNA

Nucula annulata, a deposit-feeding protobranch bivalve, was the numerically dominant species collected at the NWC site (Table 1). Also common were the surface deposit-feeding gastropoda, Acteocina canaliculata; the deposit-feeding protobranch bivalve Yoldia limatula and the errant polychaete Nepthys incisa. The FOAM site was dominated by the filter-feeding bivalve Mulinia lateralis (Table 1) which comprised 97% of the individuals. Macrofaunal density values were higher and diversity values were lower at the FOAM site compared to the NWC site (Table 2). The species richness values were approximately the same at both sites.

### B. SEDIMENT PHYSICAL PROPERTIES

Sediments collected at the NWC site were very poorly sorted, fine-skewed to strongly fine-skewed, platykurtic clayey silts or silty-clays (Appendix A). Below 1 cm, mean grain size values varied little (range: 8.11 to 8.76 $\phi$) with the highest percentage of sand and the coarsest mean grain size found in the upper 1 cm (Fig. 3). Porosity values varied little with depth with the highest values found in the upper 1 cm (Appendix B and Fig. 4). Porosity and mean grain size values were not correlated ($r^2$ = -0.0001)

Physical property values of sediments collected at FOAM site were more variable than at the NWC site. The FOAM site sediments were very poorly sorted and most were clayey silts (Appendix A). Sediments from the upper 5 cm tended to have greater percentages of sand and gravel and to be more poorly sorted, less finely skewed and more leptokurtic than sediment found deeper in the cores. Mean grain size values were lowest for sediments in the upper 5 cm of the core, increased to more than 8 between 8 and 19 cm, then decreased to approximately 7 $\phi$ at 30 cm (Fig. 5). Mean grain size and porosity values were correlated ($r^2$ = 0.77) and higher percentage porosity values were found in finer grained sediments (Appendix B and Fig. 6).

### C. SEDIMENT ACOUSTIC PROPERTIES

Sediment compressional wave velocity ($V_p$) values measured in cylindrical core liner samples with the sediment velocimeter ranged from 1476 to 1539 m/sec (Appendix C). Velocity values of the NWC site sediment decreased from 1494-1500 m/sec at 1 cm depth to 1482 m/sec at 5 cm depth (Fig. 7). Below 5 cm depth, sediment velocity values varied little. Compressional wave velocity values were also highest in the upper few centimeters at the FOAM site. FOAM sediment $V_p$ values decreased to a minimum of 1476-1482 m/sec at 9-13 cm depth, below which the sediment $V_p$ values were variable (Fig. 8).

Sediment compressional wave velocity values were not significantly correlated with mean grain size or porosity values at the NWC site, but were negatively correlated with mean grain size and porosity values at the FOAM site (Table 3).

Sediment compressional wave velocity values obtained from box core samples with the compressional wave velocity probes ranged from 1444 to 1532 m/sec and were much more variable than values obtained with the sediment velocimeter (Appendix C and Figs. 9, 10).

Table 1. Numbers of macrofauna collected from the FOAM and NWC sites on August 28-29, 1981.

| | NWC 1 | NWC 2 | NWC 3 | NWC 4 | FOAM 1 | FOAM 2 | FOAM 3 | TOTAL |
|---|---|---|---|---|---|---|---|---|
| NEMATODA | | | | | | 1 | | 1 |
| POLYCHAETA | | | | | | | | |
| *Clymenella torquata* | | | | | 1 | 3 | | 4 |
| *Clymenella zonalis* | | | | | 2 | 1 | | 3 |
| *Melinna cristata* | 5 | 1 | | 3 | | | | 9 |
| *Nephtys incisa* | 20 | 26 | 17 | 48 | 11 | 8 | 9 | 139 |
| *Pectinaria gouldi* | | | 1 | | | 1 | | 1 |
| *Sabellaria vulgaris* | | | | | 1 | | | 1 |
| *Sigambra tentaculata* | | | 3 | 1 | | | | 4 |
| *Spiochaetopterus oculatus* | | | 1 | | | | | 1 |
| GASTROPODA | | | | | | | | |
| *Acteocina canaliculata* | 37 | 32 | 40 | 82 | 4 | 1 | 3 | 199 |
| *Crepidula convexa* | | | | | 17 | 5 | 1 | 23 |
| *Haminoea solitaria* | | | | 7 | | | | 7 |
| *Nassarius trivittatus* | | 1 | | 10 | 32 | 33 | 7 | 83 |
| *Natica pusilla* | 4 | 1 | 4 | 3 | | 1 | | 13 |
| *Odostomia sp.* | | | | | 2 | | | 2 |
| *Turbonilla sp.* | | | | | | 2 | | 2 |
| PELECYPODA | | | | | | | | |
| *Mulinia lateralis* | | | | | 4794 | 5259 | 229 | 10,282 |
| *Nucula annulata* | 240 | 494 | 148 | 499 | 53 | 27 | 9 | 1,470 |
| *Modiolus modiolus* | | | | | 1 | | | 1 |
| *Pandora gouldiana* | | 2 | 1 | 1 | 54 | 24 | 1 | 83 |
| *Tellina versicolor* | | | | | 5 | 4 | 6 | 15 |
| *Yoldia limatula* | 6 | 6 | 15 | 17 | 2 | 2 | 1 | 49 |
| OSTROCODA | | | | | | | | |
| *Padocopa* | 6 | 8 | 8 | 28 | | | | 50 |
| ISOPODA | | | | | | | | |
| *Edotea sublittoralis* | | | | | | 1 | | 1 |
| AMPHIPODA | | | | | | | | |
| *Ampelisca abdita* | 2 | 11 | 2 | | | | | 15 |
| MYSIDACEA | 2 | | | | | | | 2 |
| DESCAPODA | | | | | | | | |
| *Cancer borealis* | | | | | 1 | | | 1 |
| *Crangon septemsinosa* | | | 1 | | 5 | 11 | 1 | 18 |
| *Ovalipes ocellatus* | | | 1 | | 2 | 1 | | 4 |
| *Pagurus sp.* | | | | 2 | 1 | 4 | | 7 |
| *Decapoda larvae* | | | | | 3 | 1 | | 4 |
| TOTAL | 332 | 582 | 242 | 701 | 4991 | 5390 | 267 | 12,495 |

**Table 2. Density (N/m), numbe- of species (S), diversity (H'), evenness (J') and species richness (SR) of macrofauna collected at the NWC and FOAM sites on August 27-28, 1980.**

NWC SAMPLES

| | 1 | 2 | 3 | 4 | TOTAL |
|---|---|---|---|---|---|
| $N/m^2$ | 6182 | 9778 | 4065 | 11777 | 7950 |
| S | 9 | 10 | 13 | 12 | 18 |
| H' | 1.40 | 0.97 | 1.94 | 1.79 | 1.46 |
| J' | 0.44 | 0.29 | 0.52 | 0.50 | 0.35 |
| SR | 1.39 | 1.41 | 2.19 | 1.68 | 2.26 |

FOAM SAMPLES

| | 1 | 2 | 3 | TOTAL |
|---|---|---|---|---|
| $N/m^2$ | 86228 | 90552 | 4486 | 60421 |
| S | 18 | 19 | 10 | 23 |
| H' | 0.36 | 0.24 | 0.97 | 0.31 |
| J' | 0.09 | 0.06 | 0.29 | 0.07 |
| SR | 2.02 | 2.09 | 1.61 | 2.39 |

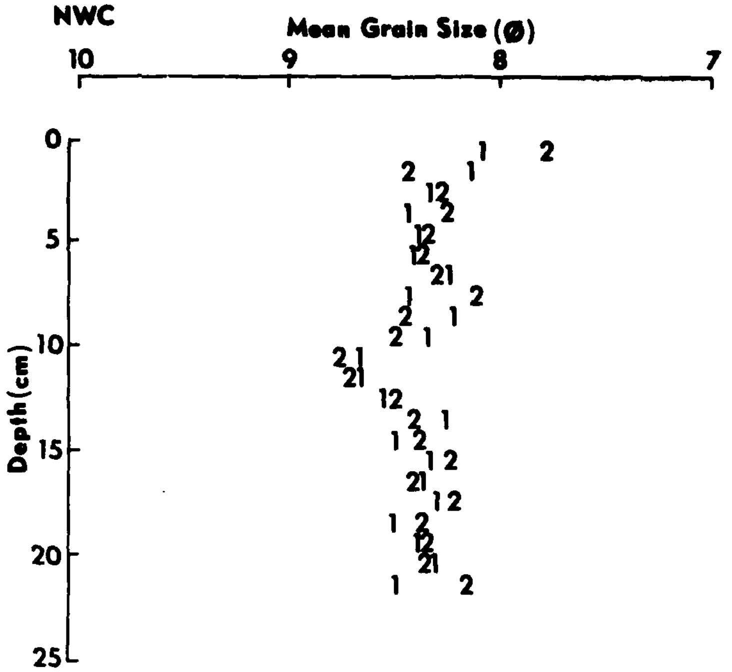



Figure 3. Vertical distribution of sediment mean grain size (ϕ) measured from cores collected at the NWC site.

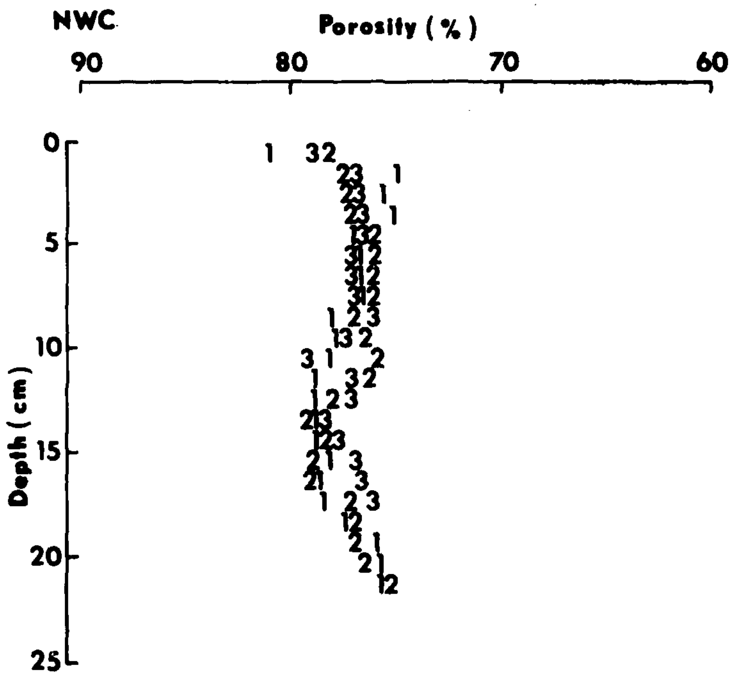



Figure 4. Vertical distribution of sediment porosity (%) measured from cores collected at the NWC site.

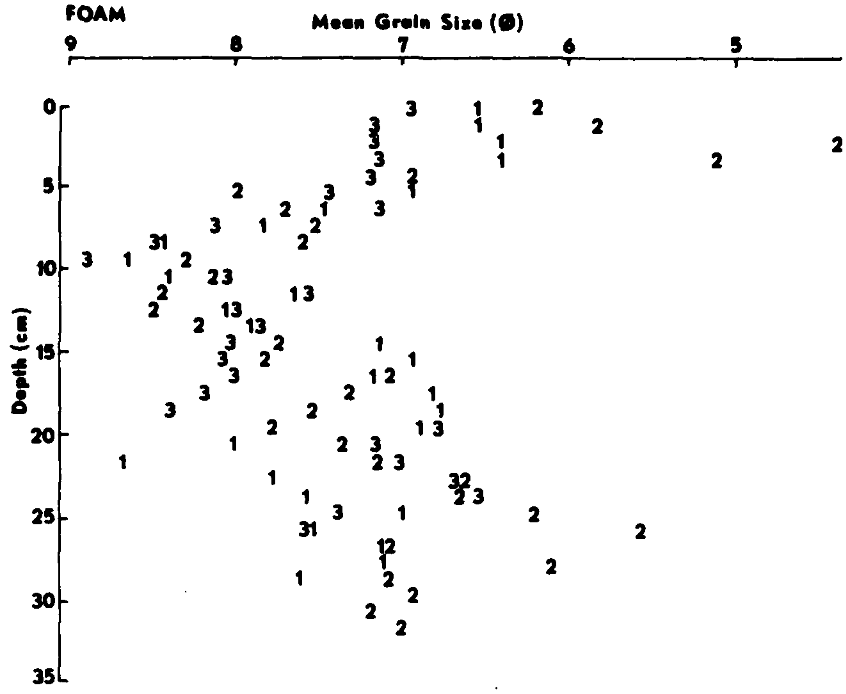



Figure 5. Vertical distribution of sediment mean grain size (ϕ) measured from cores collected at the FOAM site.

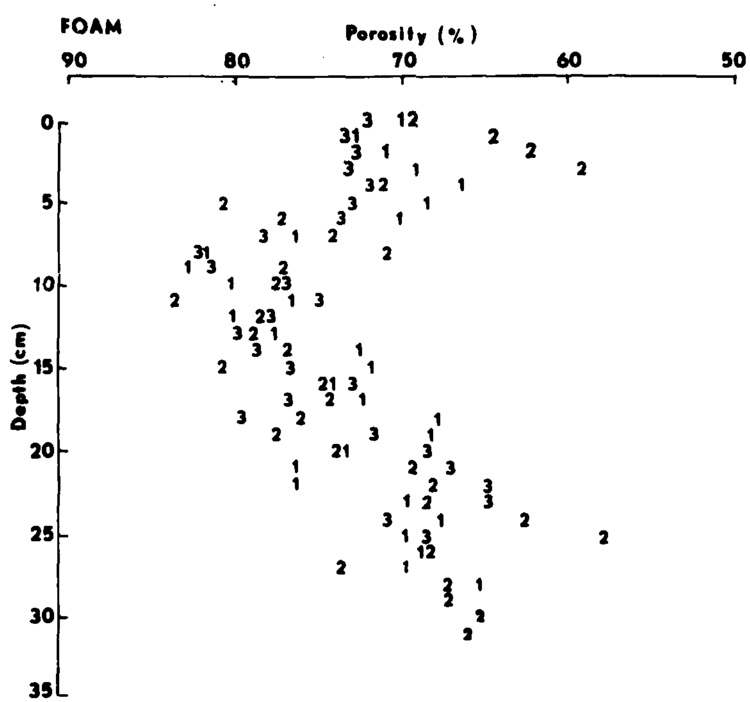



Figure 6. Vertical distribution of sediment porosity (%) measured from cores collected at the FOAM site.

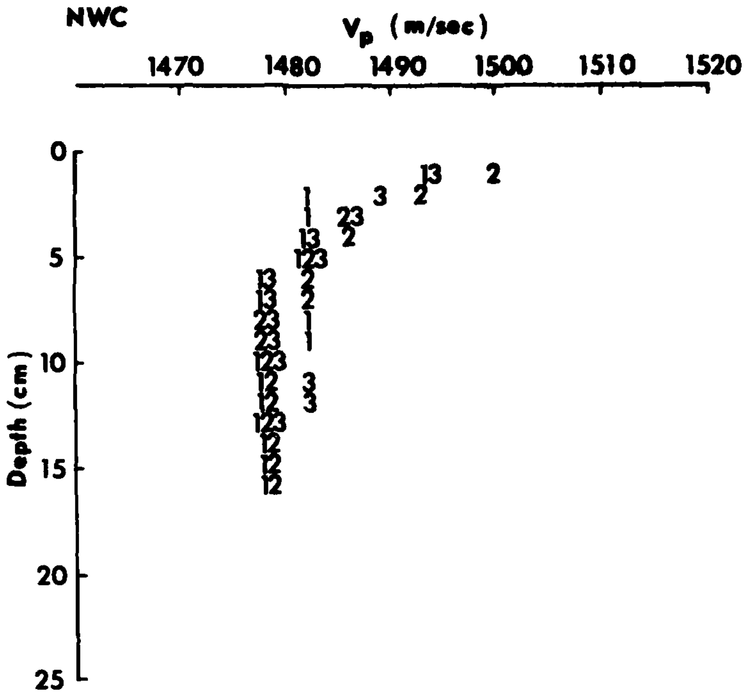



Figure 7. Vertical distribution of sediment compressional wave velocity (m/sec), measured with USI-103 sediment velocimeter, for three (5.8 cm inside diameter) core samples collected at the NWC site.

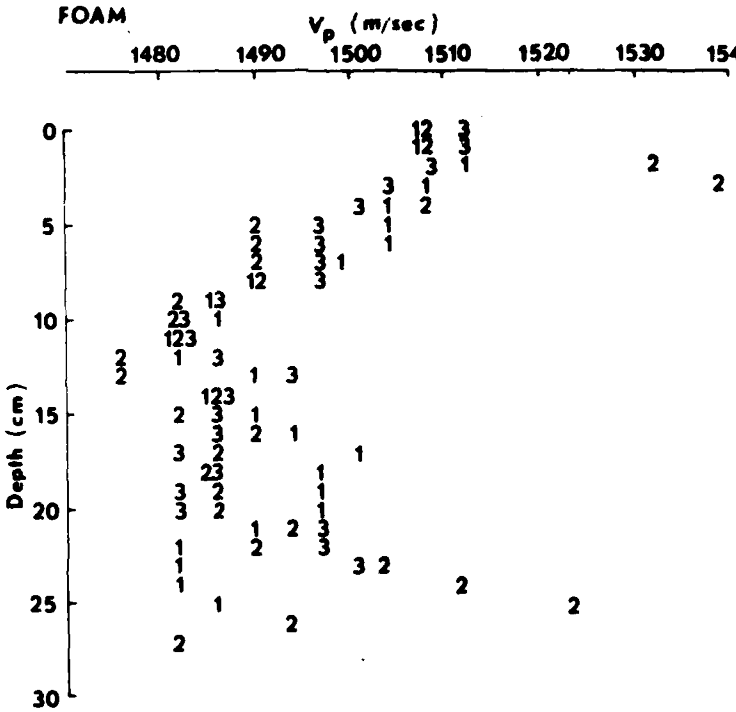



Figure 8. Vertical distribution of sediment compressional wave velocity (m/sec), measured with USI-103 sediment velocimeter, for three (5.8 cm inside diameter) core samples collected at the FOAM site.

**Table 3. Statistical correlations between sediment compressional wave velocity (m/sec), porosity (%) and mean grain size ($\phi$) for sediments collected with 5.8 cm cores from the NWC and FOAM sites, August 27-28, 1980.**

NWC

| | R | F(d.f.) | Significance |
|---|---|---|---|
| $V_p$-Porosity | -0.36 | 6.29 (1,43) | n.s. .01 |
| $V_p$-Mean Grain Size | -0.37 | 4.24 (1,27) | n.s. .01 |
| Porosity-Mean Grain Size | -0.01 | 0.4 (1,31) | n.s. .01 |

FOAM

| | R | F(d.f.) | Significance |
|---|---|---|---|
| $V_p$-Porosity | -0.68 | 62 (1,73) | > .001 |
| $V_p$-Mean Grain Size | -0.77 | 106 (1,73) | > .001 |
| Porosity-Mean Grain Size | 0.88 | 264 (1,75) | > .001 |

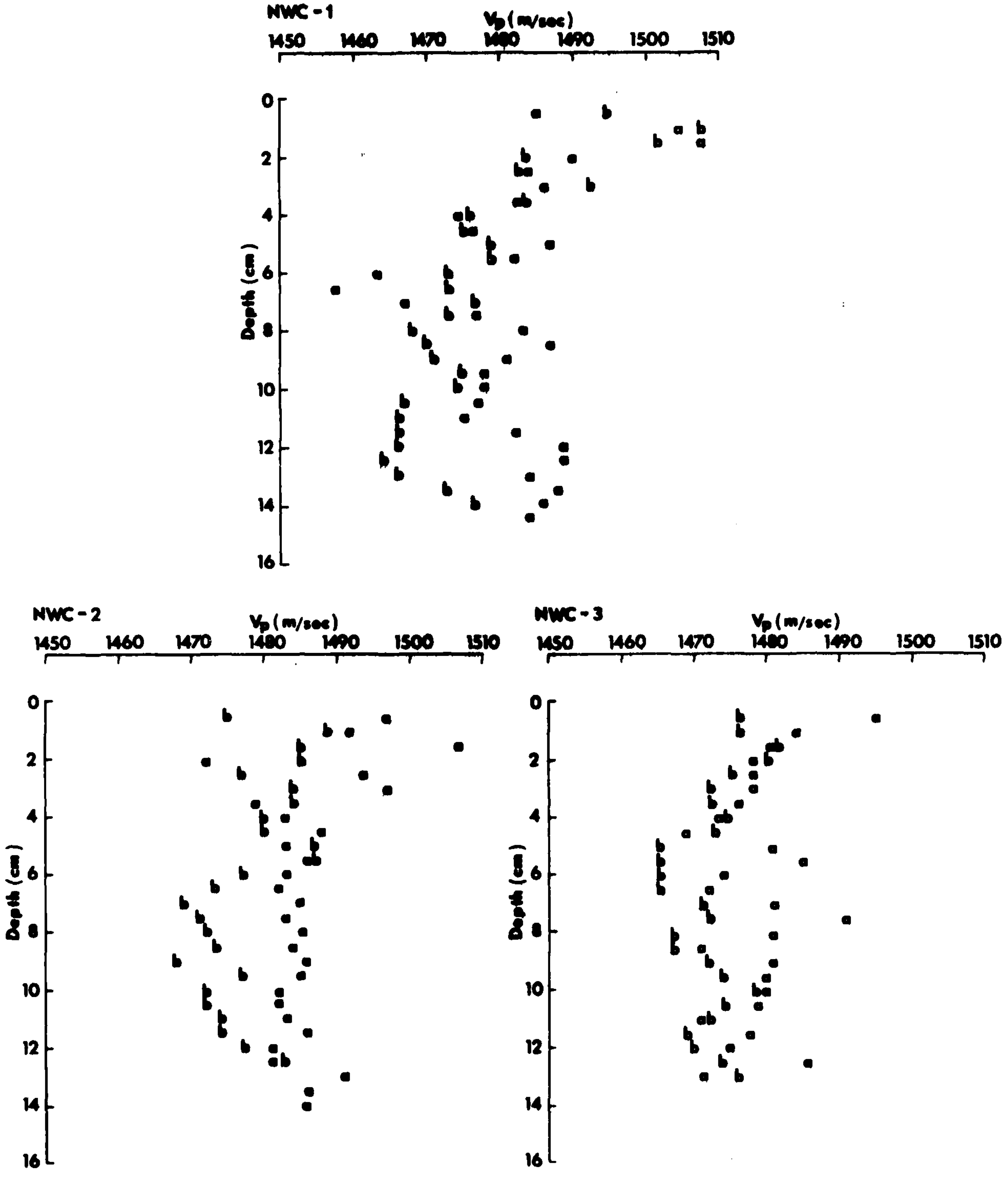



Figure 9. Vertical distribution of sediment compressional wave velocity (m/sec), measured with probes, for three box core samples collected at NWC site. Two replicate series of measurements were made from each box core.

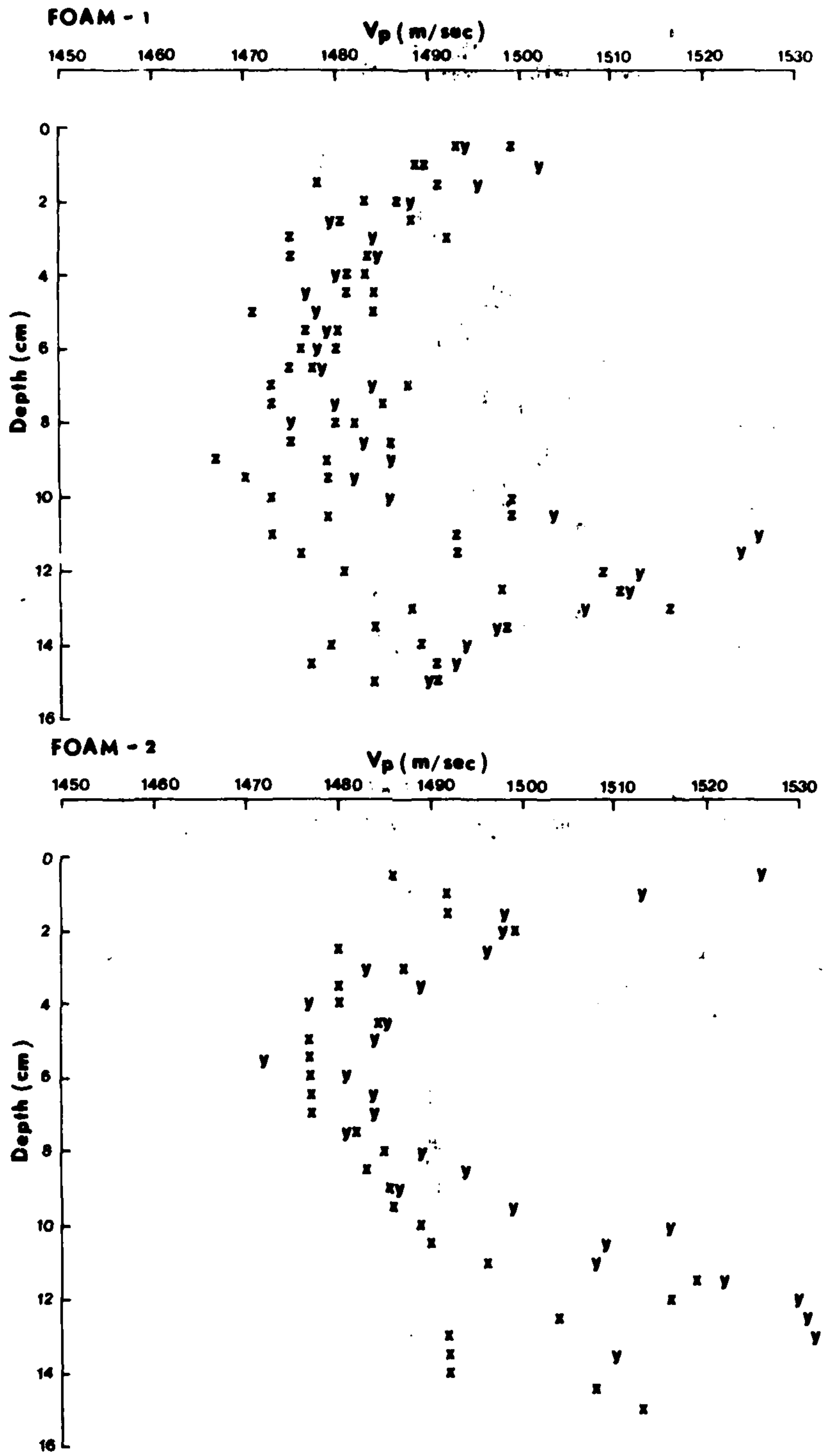



Figure 10. Vertical distribution of sediment compressional wave velocity (m/sec), measured with probes, for three box core samples collected at the FOAM site. Three replicate series of measurements were obtained from box core 1 and two series from each of box cores 2 and 3.

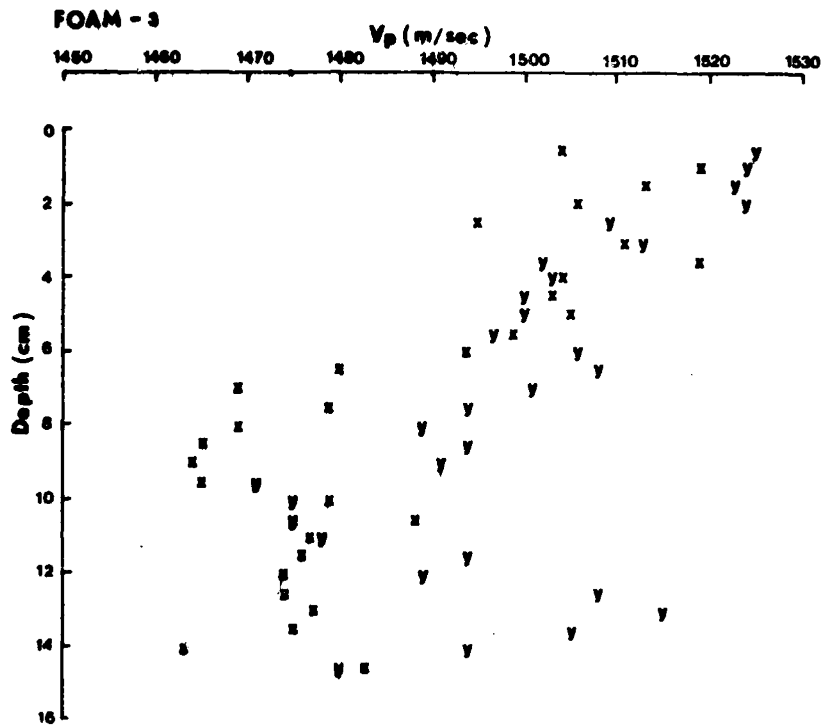



Figure 10, Continued

## D. X-RADIOGRAPHS

Two distinct sedimentary zones are evident in the X-radiographs of the FOAM box core (Figure 11). The upper zone, 5-9 cm thick, has a flocculent appearance with numerous *Mulinia lateralis* shells present. This upper zone was exposed to intense bioturbation by *M. lateralis* and is easily resuspended by storm action. The more compact zone below 5 to 9 cm is varved, the result of past episodes of erosion and deposition and has not been extensively bioturbated.

The NWC site box core has a relatively homogeneous sedimentary fabric (Fig. 12) when compared to the FOAM site. Bioturbation by *Nucula annulata* is evident in the upper 2-3 of centimeters of the core. The lighter vertical structures in the upper 7 cm of the X-radiograph are active burrows of the polychaete *Nephtys incisa* (Rhoads and Boyer, in press). Below 7 cm depth infilled burrows of *Nephtys incisa* and tubes of *Spiochaetopterus oculatus* are evident. Most of the visible shells are of dead *Mulinia lateralis*. Other dead shells include those of *Yoldia limatula*, *Nucula annulata* and *Mercenaria mercenaria*.

# IV. DISCUSSION

## A. SPATIAL VARIABILITY OF COMPRESSIONAL WAVE VELOCITY

Considerable spatial variability in values of compressional wave velocity was measured in sediments collected from the NWC and FOAM sites (Figs. 7, 8, 9 and 10).

Velocity values measured by the compressional wave probes (Figs. 9 and 10) were more variable than velocity values measured by the velocimeter (Figs. 7 and 8) because of presence of fine scale differences in sediment physical properties resulting from a random distribution of burrow structure, fecal material, dead shell material and live animals (Figs. 11 and 12). The longer pathlength over which the sediment velocimeter measures time delay probably integrates these fine scale differences in physical and acoustic properties.

The vertical and horizontal variability in compressional wave velocity correlates with the spatial variability in sediment physical properties such as porosity and mean grain size. The FOAM site had greater variability in compressional wave velocity than the NWC site because of the greater variability in sediment physical properties. The interaction of hydrodynamic and biological processes which cause this variability will be discussed in the next section.

It is obvious from these data that caution must be exercised when sediment acoustic properties are predicted from sediment physical properties for shallow water coastal sediments. Techniques used for prediction of acoustic properties of deep-sea sediment properties (see Hamilton, 1974, for review) assume little spatial variability of sediment physical properties in the upper few meters of sediment and for horizontal distances of at least hundreds of meters if not kilometers. Our data have shown considerable differences in physical and acoustic properties within a few centimeters vertically and within a few meters horizontally. The pathlength over which physical and acoustic sediment properties are measured also apparently effects the variability of results. The longer pathlength measurements integrate small scale differences in sediment physical and acoustic properties and reduce the variability of measured properties. Temporal changes in sediment physical and acoustic properties, as discussed in the next section, must also be investigated if acoustic predictions are to be valid for times other than those sampled.

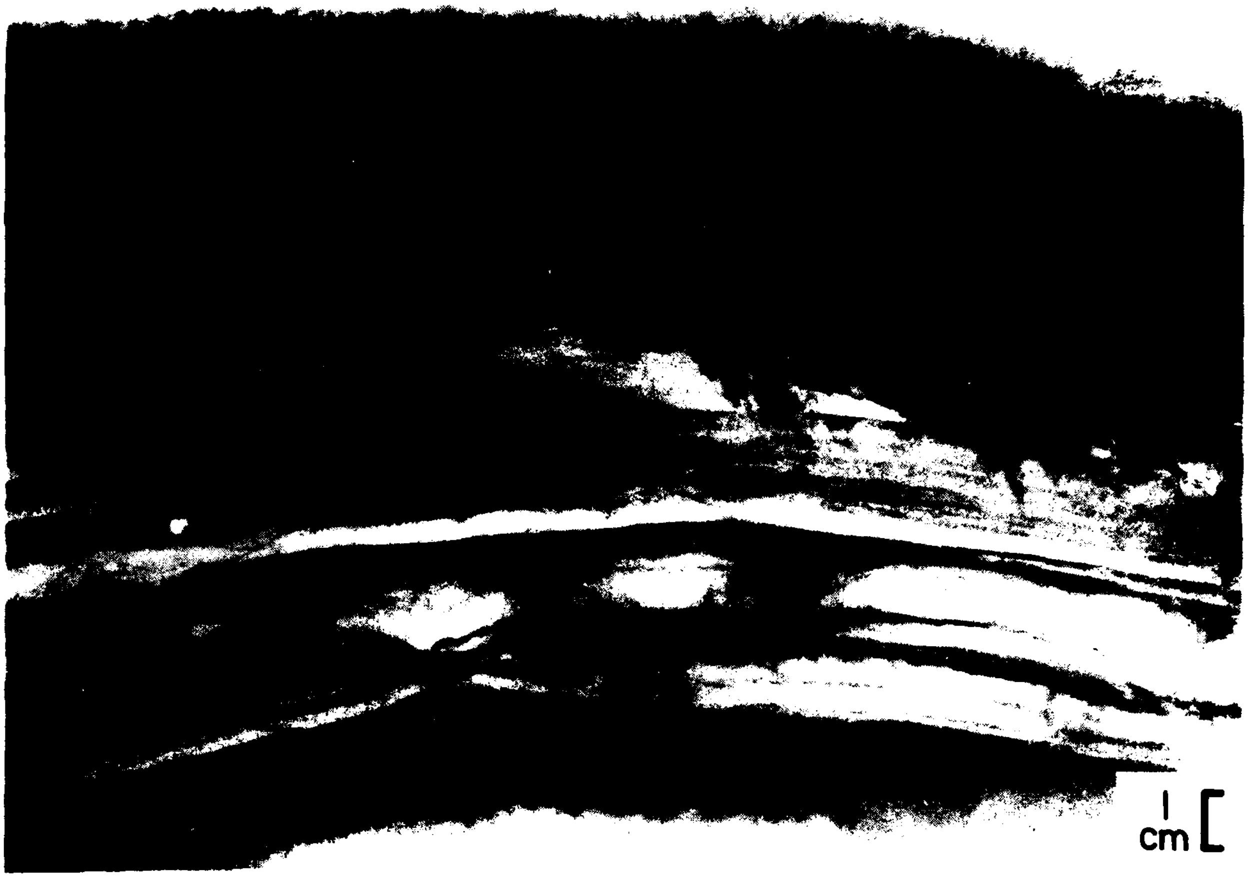



Figure 11A. X-radiograph of FOAM site, showing laminated sediment lying below bioturbated fluffy layer.

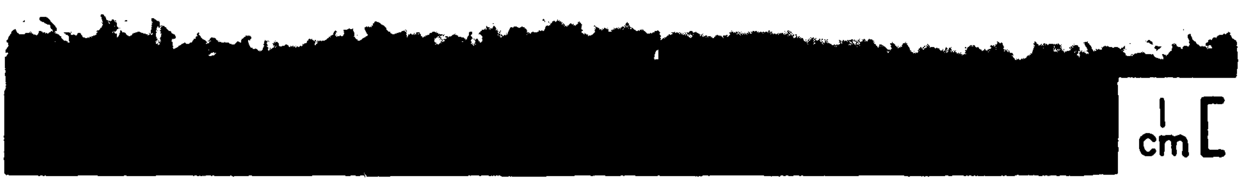



Figure 11B. X-radiograph of upper 3 cm of same FOAM site core showing the dense population of Mulinea lateralis (exposure time reduced).


Figure 12. X-radiograph of bioturbated sediment fabric at NWC site.

The sampling design required for geoacoustic modeling depends on the type of prediction needed. Support of high frequency (10 kHz to 200 kHz) acoustic experiments requires understanding the variability of fine-scale sediment physical and acoustic properties because of the short wavelengths involved. Lower frequency acoustic experiments can employ techniques which utilize longer pathlength measurements. Most experiments probably require a combination of methods. Data used to construct sediment physical property-acoustic property models should be obtained from areas of low spatial acoustic-physical property variability.

## B. COMPARISON OF NWC AND FOAM SITES

The NWC site was dominated by deposit feeding protobranch bivalves which intensely rework the upper few centimeters of sediment. This reworking can destroy any primary sediment structure formed by suspension and redeposition of sediment by occasional storms. Aller and Cochran (1976) found fine laminations to depths of 2 cm in X-radiographs of NWC sediments obtained after a fall northeastern storm. Destruction of these laminations was evident five days after the storm, and by the time of winter sampling four months later, these fine laminations had been completely destroyed by intense biological reworking. Except for storms of hurricane force winds, it is doubtful that erosion-deposition processes can create primary sediment laminations below 2 cm at the NWC site (Aller and Cochran, 1976; McCall, 1978); therefore, bioturbation in this zone by *Nucula annulata* and *Yoldia limatula* creates the uniform spatial distribution of physical and acoustic properties measured in the core liner samples. A 150 cm long core from the NWC site, examined by Benninger *et al.* (1979) yielded no fine laminations throughout its length, indicating that these processes have continued for many years.

On a finer scale (the probe measurements), the NWC site is characterized by variability in values of compressional wave velocity. This fine-scale variability was probably the result of reworking below the *Nucula-Yoldia* zone by the deep-burrowing polychaete *Nepthys incisa* and tube dwelling polychaetes *Spiochaetopterus oculatus* and *Melinna cristata*. Open and infilled burrow and feeding structures are evident to depths of 15 cm in our X-radiograph (Fig. 12) and to depths of 25 cm in X-radiographs taken of sediment at NWC site by Aller and Cochran (1976). Also evident in all X-radiographs are abundant shells of *Mulinia lateralis*, *Yoldia limatula*, *Nucula annulata*, *Mercenaria mercenaria*, other bivalves and gastropods. Most of the shells occur at random orientations in our X-radiograph, indicating that the sediment in this zone is mixed by bioturbation. Benninger *et al.* (1979) estimated from excess Lead-210 measurements that the zone from 3 cm to 10 cm at the NWC site is mixed at a rate of only 1 to 3 percent of the mixing rate of the *Nucula-Yoldia* zone. This mixing is enough to yield a uniform distribution of physical and acoustic properties in this zone at the core liner sampling scale and a random distribution of physical and acoustic properties at the shorter length scale measured by the probes. Below 25 cm depth, large burrow structures made by the deep-dwelling stomatopoda, *Squilla empusa*, are not destroyed by bioturbation (Benninger *et al.*, 1979; Myers, 1979), and physical and acoustic properties may be more variable.

The FOAM site was characterized by fine scale and large scale horizontal and vertical variability in values of compressional wave velocity. The vertical variations in velocity values probably resulted from a combination of biological and hydrodynamic processes. The FOAM site is shallower than the NWC site and is subject to more frequent and severe episodes of erosion and deposition (Rhoads and Boyer, in press). These hydrodynamic processes created the laminated zone evident in X-radiographs. The FOAM site is usually dominated by pioneering tube dwelling

polychaetes and amphipod species such as Streblospio benedicti, Capitella capitata, Owenia fusiformis and Ampelisca abdita (Rhoads and Boyer, in press; McCall, 1977). These animals typically feed near the sediment surface or filter particles from the water column and do not mix the sediment to any appreciable depth (Rhoads et al., 1977; Rhoads, et al., 1978). This lack of deep biological sediment mixing at the FOAM site probably preserves the hydrodynamically created laminations.

At our time of sampling, biological mixing activities (bulldozing) by Mulinia lateralis had destroyed the sediment laminations at locations where several of the cores were collected. This activity increased porosity values, decreased mean grain size (greater mean phi values) and decreased values of compressional wave velocities to depths of 6 to 10 cm. The combination of biologically mixed surface sediments and hydrodynamically laminated deeper sediments yielded a variable vertical distribution of values of physical and acoustic properties (Figs. 5, 6, 8, 10).

The horizontal distribution of physical and acoustic properties of the FOAM site was quite variable. Mulinia lateralis was the dominant species collected in the FOAM samples but this bivalve was not uniformly distributed over the FOAM site on the scale of meters (our cores), or hundreds of meters (Rhoads and Germano, in press). FOAM box cores 1 and 2, which contained high densities of Mulinia lateralis (50,000 individuals/$m^2$), had high surface porosity values (77-81%) (Fig. 13) and slower compressional wave velocity (1480 to 1500 m/sec) (Fig. 10a, b). FOAM box core 3, which contained a lower density of Mulinia lateralis (2,000 individuals/$m^2$) had lower surface porosity values (63 to 68 percent) and faster compressional wave velocity (1500 to 1530 m/sec) (Fig. 10c).

Spatial and seasonal changes in species composition also result in concurrent seasonal changes in physical and acoustic properties and in the seasonal erodibility of surface sediments. Rhoads and Germano (in press) found that the sediment occupied by M. lateralis in August 1980 experienced greater erosion by November 1980 than sediment of the surrounding bottom. This interaction of biological and hydrodynamic processes created a much greater spatial and temporal variability in physical and acoustic properties at the FOAM site than at the NWC site.

## C. THE PREDICTED EFFECTS OF BIOLOGICAL PROCESSES ON SEDIMENT ACOUSTIC PROPERTIES.

We predicted that bioturbation by Nucula annulata would decrease compressional wave velocity in unconsolidated marine sediments (Richardson and Young, 1980). We based this prediction on previously measured changes in porosity attributed to N. annulata bioturbation (Rhoads and Young, 1971), and a compression wave velocity-porosity predictor equation for continental terrace sediments (Hamilton, 1974).

Using mean porosity values from NWC site box core sediment samples and Hamilton's (1974) prediction equator, we calculated that for this study predicted compressional wave velocity values should be 1507 m/sec in the upper centimeter of sediment and a maximum of 1520 m/sec at 7 to 9 cm (Fig. 14). The predicted $V_p$ values for sediments collected with the core liners were calculated to range from 1512 to 1518 m/sec with the lowest value in the upper centimeter of sediment (Fig. 15). These calculated values are 15 m/sec higher than measured compressional wave velocities for the upper centimeter of the NWC sediment and 30 to 45 m/sec higher than compressional wave velocities measured for sediment below the upper 2 cm of the sediment surface (Figs. 14 and 15).

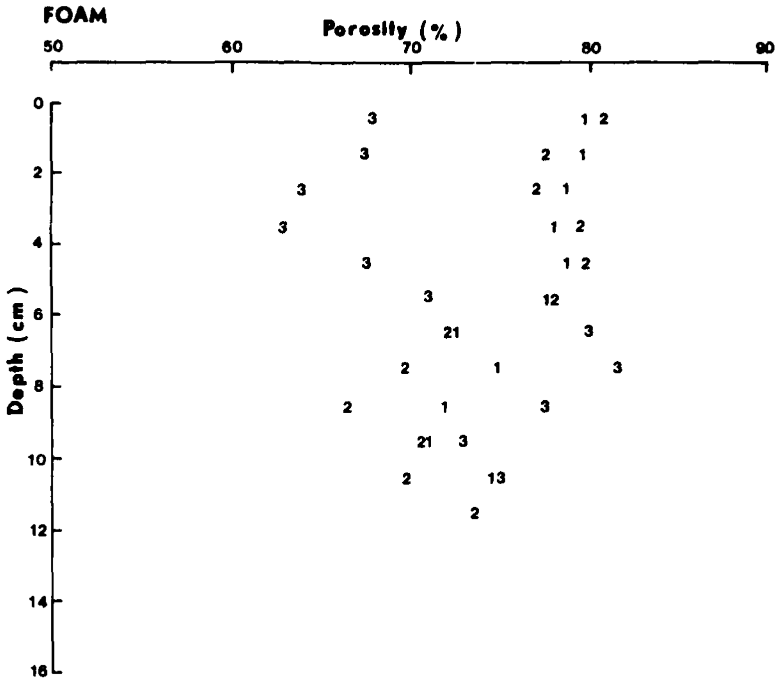



Figure 13. Vertical distribution of porosity (%) measured from three box cores collected from the FOAM site.

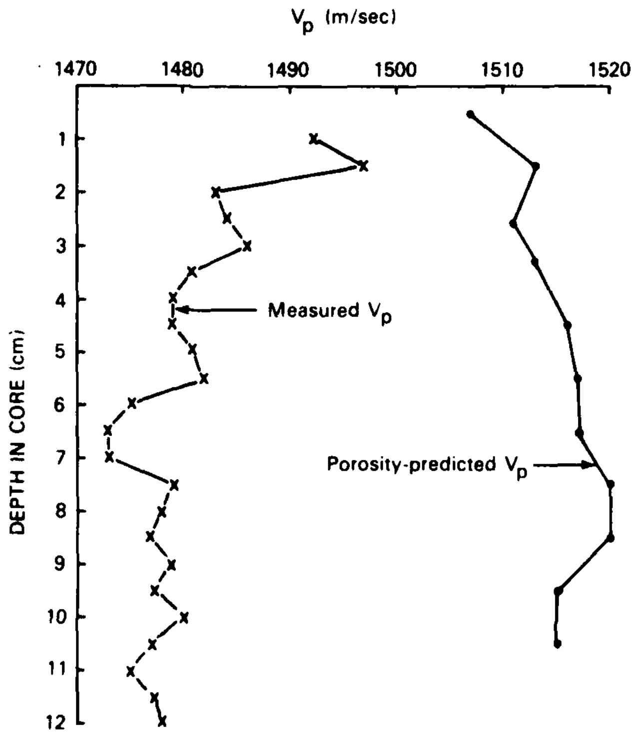



Figure 14. Predicted and measured compressional wave velocity values (m/sec) for sediments collected with box cores at the NWC site. Predictions based on Hamilton's (1974) $V_p$-porosity and $V_p$-mean grain size predictor equations.

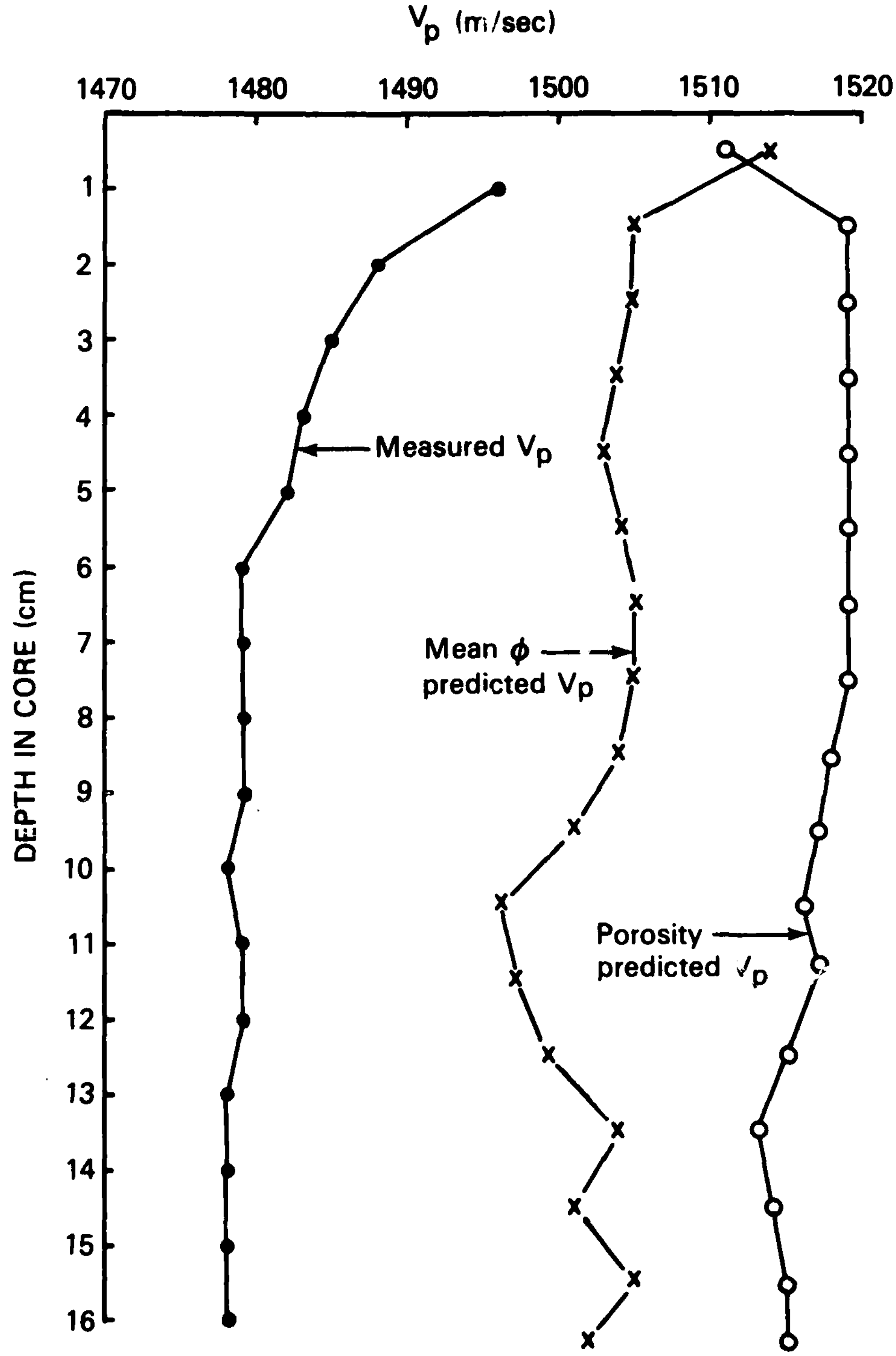



**Figure 15. Predicted and measured compressional wave velocity values (m/sec) for sediments collected with core liner samples at the NWC site. Predictions based on Hamilton's (1974) $V_p$-porosity and $V_p$-mean grain size predictor equations.**

If Hamilton's (1974) mean grain size-$V_p$ predictor equation is used, calculated compressional wave velocities for sediments collected with the core liner samples would be 1514 m/sec in the upper centimeter of the sediment and a mean of 1503 m/sec below 2 cm depth in the core liner samples (Fig. 15). The values were only 10 to 25 m/sec higher than the measured velocities. Perhaps more importantly the measurements and the predictions based on mean grain size-velocity are both high in the top centimeter and decrease with depth. Velocities predicted by the porosity-$V_p$ equation were lowest in the upper centimeter. In all three predicted examples, measured compressional wave velocities were within the standard error of the predictor equations (Morris et al., 1978).

Sediment reworking by Nucula annulata at NWC site did not increase porosity in the upper few centimeters, as predicted by Richardson and Young (1980). Specimens of N. annulata, at NWC site, were from a single year class and were small (1.90 mm length; range 0.86 to 3.84 mm; n = 100) compared to adult sizes of 5 to 8 mm length (Hampson, 1971). Fecal pellets produced by adult specimens of N. annulata are 300 μm long and have a diameter of 150 μm (personal observations). Fecal pellets produced by a 1.9 mm long specimens of N. annulata are much smaller. The small sizes of specimens of N. annulata also restrict the depth of biological reworking. Smaller specimens of N. annulata, therefore, do not create an extensive, uncompacted, granular surface, which increases porosity and reduces compressional wave velocity, as was predicted for larger specimens (Richardson and Young, 1980). When the population of N. annulata reaches adult size, a 2-3 cm deep, low-porosity, pelletized zone would likely be produced, and compressional wave velocities values would be lower than when we sampled in August at the NWC site.

Compressional wave velocity values were not predicted by Richardson and Young (1980) for macrofaunal assemblages as found at the FOAM site. As suggested by Rhoads and Boyer (in press), it is impossible to predict which opportunistic species from Long Island Sound will dominate the FOAM site at any given time. We would expect sediment physical and acoustic properties to be much different if the FOAM site were dominated by tube dwelling polychaetes and amphipods instead of filter-feeding bivalves. Using the logic employed by Richardson and Young (1980), we would expect specimens of Mulinia lateralis to increase porosity in the surficial sediments, which would result in a lower compressional wave velocity and increased sediment erodibility. Tube-dwelling polychaetes, on the other hand, tend to stabilize the sediment surface preserving hydrodynamically created laminations. We would expect this stabilization effect to also preserve the physical or acoustic properties below the upper cm of sediment. Activities of M. lateralis increased porosity in the upper 6-9 cm of the sediment. In the two box cores dominated by M. lateralis, porosity values in the upper 6 cm of sediment were 80%, while sediment with a lower abundance of M. lateralis had porosity values of 65% to 70% (Fig. 13). Porosity values of 65% to 70% are typical of FOAM summer locations dominated by surface feeding pioneering species (Aller et al., 1980).

Using Hamilton's (1974) empirical relationships and porosity values of 80%, the calculated compressional wave velocity values for sediments densely populated by M. lateralis would be 1511 m/sec. Using porosity values of 65 to 70% for more typical FOAM locations, the predicted $V_p$ values would be 1539 to 1562 m/sec. Compressional wave velocities of 1500 m/sec were measured for dense patches of M. lateralis and $V_p$ values of 1520 to 1530 m/sec were measured for the more typical FOAM conditions. Compressional wave velocities as high as 1540 m/sec were measured for sediments in one core liner sample with low densities of M. lateralis (Fig. 8).

The compressional wave velocity values measured in samples collected at the FOAM site were 10 to 20 m/sec lower than those predicted by Hamilton's (1974) empirical predictor equation, but were within the standard error of the predictor equations (Morris et al., 1978). More importantly, the direction of change for compressional wave velocity was correctly predicted by the logic previously employed by Richardson and Young (1980). Below the 6- to 9-cm-thick flocculent bioturbated layer, porosity values decrease from 80% to 65% at 30 cm. This reduction in porosity is the result of a reduction in mean grain size and compaction. As would be expected, there was a general concurrent increase in compressional wave velocity.

## V. CONCLUSIONS

- The NWC site was characterized by uniform distribution of physical and acoustic properties on a scale of a few centimeters. Considerable fine-scale structure resulting from biological activity was also evident. Sediment mixing in the 0-3 cm zone by *Nucula annulata* and *Yoldia limatula* and in the 3 to 15 cm zone by *Nepthys incisa*, *Spiochaetopterus oculatus*, and *Melinna cristata* destroyed primary physical and acoustic structure induced by erosional and depositional events. Bioturbation by these same species created considerable random variability in fine-scale physical and acoustic structure by creating burrows, tubes, and feeding voids and mixing shell remains throughout the upper 15 cm. Below 25 cm large burrow structures constructed by deep burrowing species were preserved, and physical and acoustic properties are probably variable on the scale of a few centimeters.

- The FOAM site was characterized by both fine- and large-scale, temporal and spatial (horizontal and vertical) variability in physical and acoustic properties. Hydrodynamic processes created laminated zones of different physical and acoustic properties. The unpredictable occurrence of species dominating the FOAM site yielded an areal and temporal variability in surface physical and acoustic properties.

- Compressional wave velocity measurements were lower than predicted by Hamilton's (1974) predictor equations.

- Bioturbation by benthic animals alters the acoustic properties of unconsolidated marine sediments by their direct effect on sediment physical properties and by their influence on erosion and depositional events.

- The physical and acoustic properties of coastal marine sediments are controlled by the interaction of biological and hydrodynamic processes. Future studies on the relationships between these properties should lead to improved predictive models of the spatial and temporal distribution of physical and acoustic properties of sediments in coastal waters.

- It is obvious from these data that caution must be exercised when sediment acoustic properties are predicted from sediment physical properties for shallow-water coastal sediments. Sampling designs which define either small-scale sediment property variability or make measurements over long pathlengths must be used to predict shallow-water sediment acoustic properties.

## VI. REFERENCES


Aller, R. C. (1978a). Experimental Studies of Changes Produced by Deposit-feeders on Pore Water, Sediment, and Overlying Water Chemistry. Am. J. Sci., 278: 1185-1234.

Aller, R. C. (1978b). The Effects of Animal-sediment Interactions on Geochemical Processes Near the Sediment-water Interface. In: M. L. Wiley (ed.), Estuarine Interactions, Academic Press, N.Y., p. 157-172.

Aller, R. C. and J. K. Cochran (1976). $^{234}Th/^{238}U$ Disequilibrium in Near Shore Sediments: Particle Reworking and Diagenetic Time Scales. Earth Planet. Sci. Lett., 29:27-50.

Aller, R. C., L. K. Benninger and J. K. Cochran (1980). Tracking Particle Associaciated Processes in Nearshore Environments by Use of $^{234}Th/^{238}U$ Disequilibrium. Earth Planet. Sci. Lett., 47:161-175.

Benninger, L. K., R. C. Aller, J. K. Cochran and K. K. Turekian (1979). Effects of Biological Sediments Mixing on the $^{210}Pb$ Chronology and Trace Metal Distribution in a Long Island Sound Sediment Core. Earth Planet. Sci. Lett., 432:241-259.

Benoit, G. J., K. K. Turekian and L. K. Benninger (1979). Radiocarbon Dating of a Core from Long Island Sound. Est. Coast. Mar. Sci., 9:171-180.

Bokuniewicz, H. J., R. Gordon and D. C. Rhoads (1975). Mechanical Properties of the Sediment-water Interface. Mar. Geol., 18:263-278.

Folk, R. L. (1965). Petrology of Sedimentary Rocks. Hemill's, Austin, Texas.

Folk, R. L. and W. C. Ward (1957). Brazos River Bar, a Study in the Significance of Grain Size Parameters. J. Sed. Pet., 27:3-26.

Goldhaber, M. B., R. C. Aller, J. K. Cochran, J. K. Rosenfeld, C. S. Martens and R. A. Berner (1977). Sulfate Reduction, Diffusion and Bioturbation in Long Island Sound Sediments: Report of the FOAM Group. Am. J. Sci., 277:193-237.

Hampson, G. R. (1971). A Species Pair of the Genus Nucula (Bivalvia) from the Eastern Coast of the United States. Proc. Malac. Soc. Lond., 39:333-342.

Hamilton, E. L. (1971). Elastic Properties of Marine Sediments. J. Geophys. Res., 76:579-603.

Hamilton, E. L. (1974). Geoacoustic Models of the Sea Floor. In: L. Hampton (ed.), Physics of Sound in Marine Sediments, Plenum Press, New York, NY, 181-221.

Lambert, D. N. and R. H. Bennett (1972). Tables for Determining Porosity of Deep-Sea Sediments from Water Content and Average Grain Size Density Measurements. NOAA Technical Memo. ERL AOML-17.

Lloyd, M., and R. J. Ghelardi (1964). A Table for Calculating the "Equitability" Component of Species Diversity. J. Anim. Ecol., 33:217-225.

Margalef, R. (1958). Informational Theory in Ecology. Gen. Syst., 3:36-71.

McCall, P. L. (1977). Community Patterns and Adaptive Strategies of the Infaunal Benthos of Long Island Sound. J. Mar. Res., 35: 221-266.

McCall, P. L. (1978). Spatial-temporal Distributions of Long Island Sound Infauna: The Role of Bottom Disturbance in a Nearshore Marine Habitat, 191-219. In: M. L. Wiley (ed.), Estuarine Interactions, Academic Press, New York.

Morris, H. E., E. L. Hamilton, H. P. Bucker, and R. T. Bachman (1978). Interaction of Sound with the Ocean Bottom: A Three-year Summary. Naval Ocean System Center Technical Report 242:77.

Myers, A. C. (1979). Summer and Winter Burrows of a Mantis Shrimp Squilla Empusa, in Narrangansett Bay, Rhode Island. Est. Coast. Mar. Sci., 8:87-98.

Pielou, E. C. (1966). The Measurement of Diversity in Different Types of Biological Collections. J. Theor. Biol., 13:131-144.

Rhoads, D. C. (1974). Organism-sediment Relations on the Muddy Sea Floor. Oceanogr. Mar. Biol. An. Rev., 12:263-300.

Rhoads, D. C., R. C. Aller and M. B. Goldhaber (1977). The Influence of Colonizing Benthos on Physical Properties and Chemical Diagenesis of the Estuarine Seafloor, 113-138. In: B. C. Coull (ed.), Ecology of Marine Benthos, Belle W. Baruch Library in Marine Science, No. 6, U. of So. Carolina Press, Columbia, S.C.

Rhoads, D. C., J. Y. Yingst and W. J. Ullman (1978). Seafloor Stability in Central Long Island Sound: Part I: Temporal Changes in Erodibility of Fine-grained Sediment, 221-244. In: M. L. Wiley (ed.), Estuarine Interaction Academic Press, New York.

Rhoads, D. C. and L. F. Boyer (in press). The Effects of Marine Benthos on Physical Properties of Sediments: A Successional Perspective. In: McCall, P. L. and Tevesz (eds.), Contribution to Plenum Biology Series, Vol. 2.

Rhoads, D. C. and J. D. Germano (in press). Characterization of Organism-sediment Relations Using Sediment Profile Imaging: An Efficient Method of Remote Ecological Monitoring of the Seafloor (REMOTS SYSTEM). Marine Ecology Progress Series, 1982.

Richardson, M. D. and D. K. Young (1980). Geoacoustic Models and Bioturbation. Mar. Geol., 38:205-218.

Shannon, C. E. and W. Weaver (1963). The Mathematical Theory of Communication. Univ. Illinois Press, Urbana.

Wilson, W. D. (1962). Table of Sound Speed in Sea Water. U. S. Naval Oceanogr. Off. Spec. Publ., 58:57 pp.

Yingst, J. Y. and D. C. Rhoads (1978). Seafloor Stability in Central Long Island Sound: Part II: Biological Interactions and Their Potential Importance for Seafloor Erodibility, p. 245-260. In: M. L. Wiley (ed.), Estuarine Interaction Academic Press, New York.

I

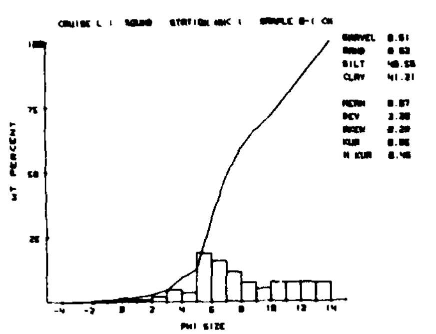
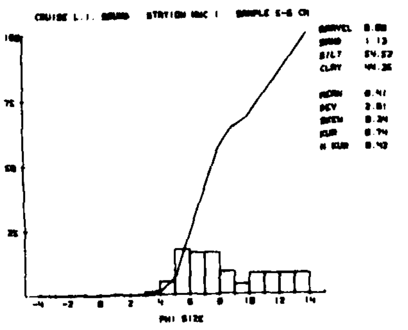
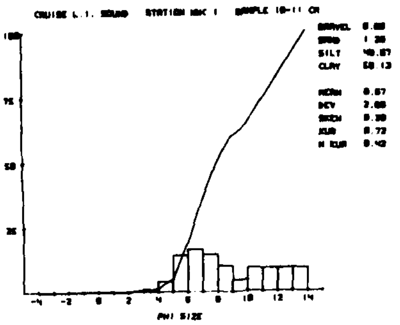
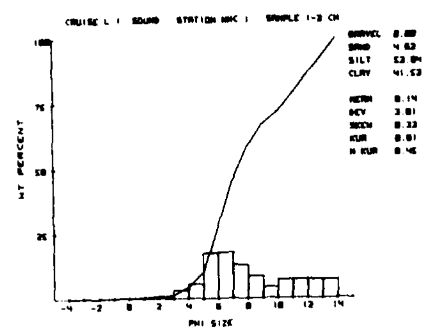
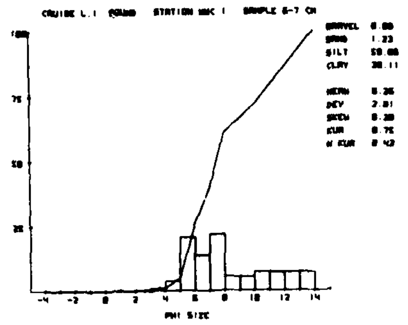
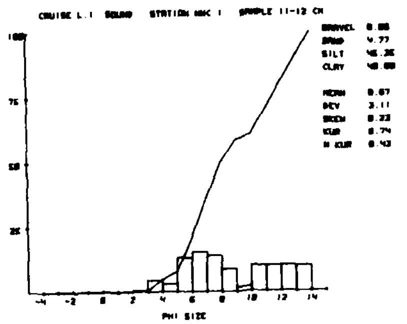
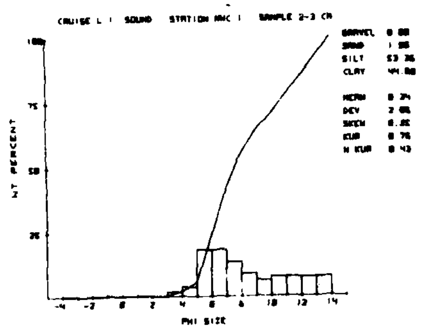
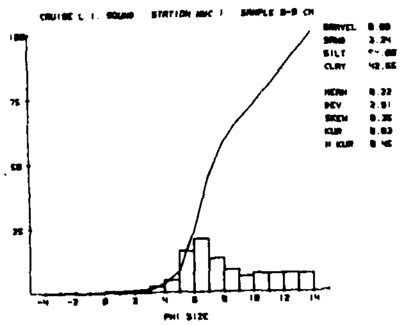
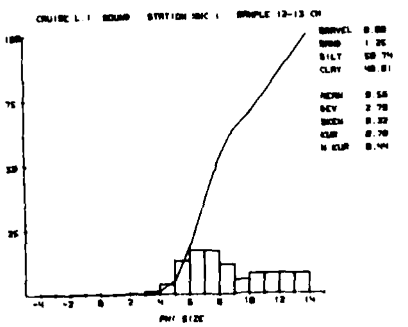
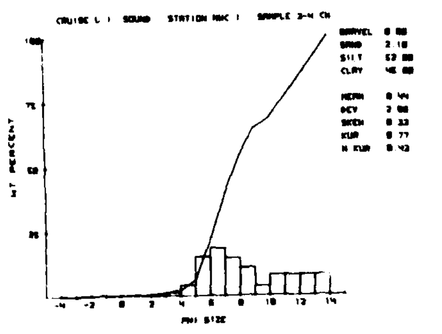
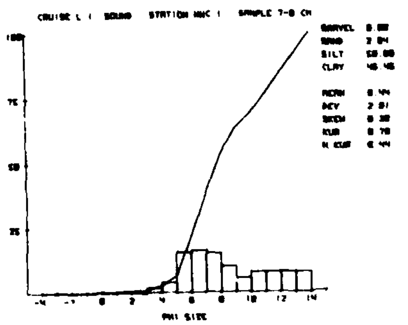
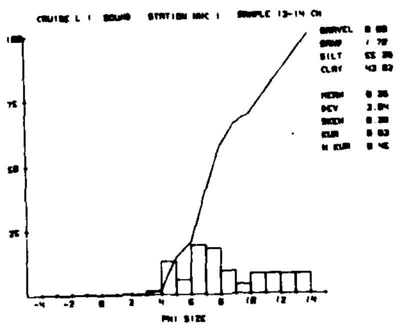
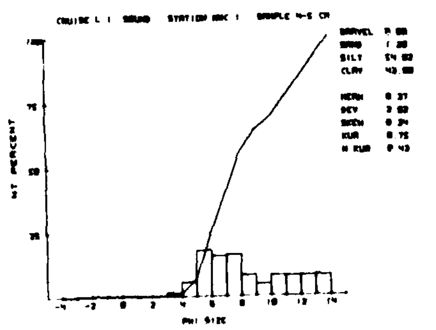
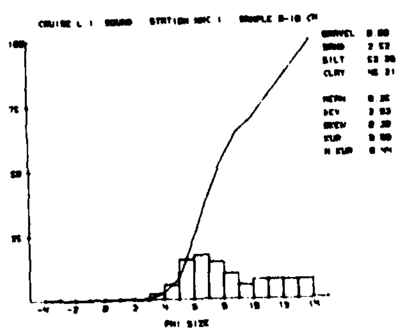
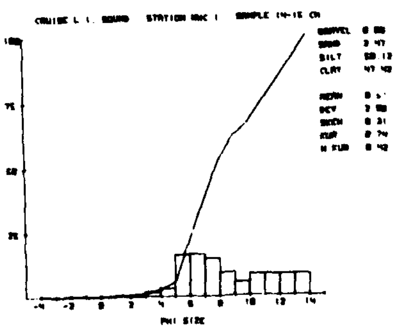
APPENDIX A

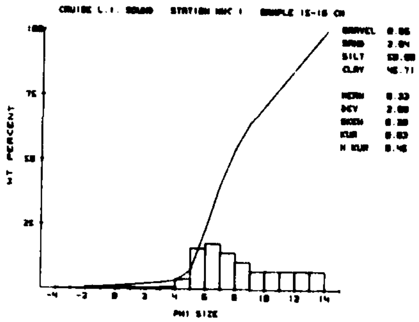
GRAIN SIZE DISTRIBUTION DATA FOR CORES

COLLECTED AT FOAM AND NWC SITES

Grain size data plotted as weight percent histogram and cumulative weight histogram for all phi sizes through 14 $\phi$. Also included are percentage gravel, sand, silt and clay and Folk and Ward's mean phi, standard deviation, skewness, kurtosis and normalized kurtosis. Data include two cores from the NWC site and 3 cores from the FOAM site.


| Core | Pg |
|---|---|
| Station NWC 1, Samples 0-15 cm | 28 |
| Station NWC 1, Samples 15-22 cm | 29 |
| Station NWC 2, Samples 0-15 cm | 30 |
| Station NWC 2, Samples 16-22 cm | 31 |
| Station FOAM 1, Samples 0-15 cm | 32 |
| Station FOAM 1, Samples 15-29 cm | 33 |
| Station FOAM 2, Samples 0-15 cm | 34 |
| Station FOAM 2, Samples 15-30 cm | 35 |
| Station FOAM 3, Samples 0-15 cm | 36 |
| Station FOAM 3, Samples 15-26 cm | 37 |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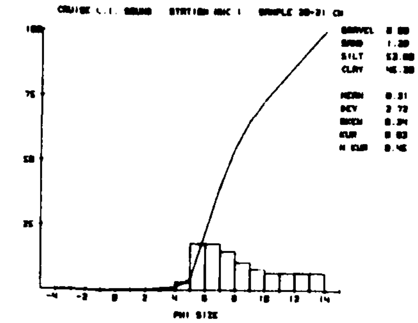
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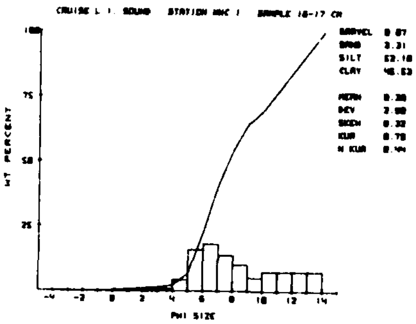
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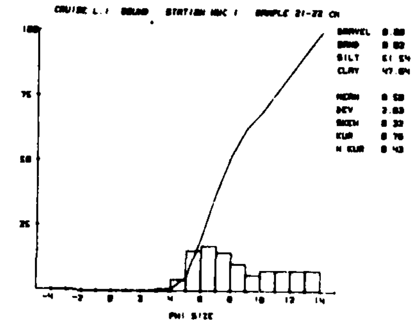
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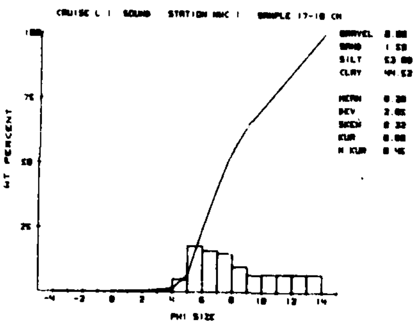
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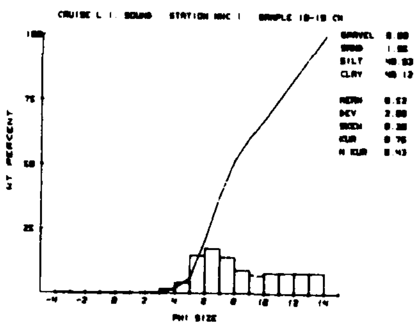
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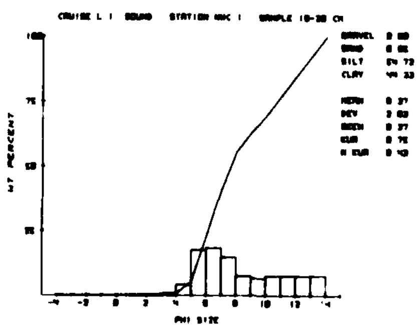
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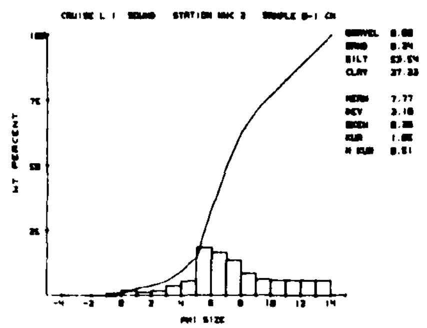
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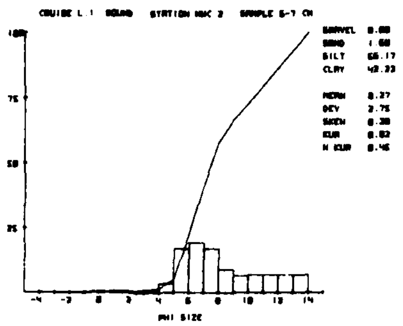
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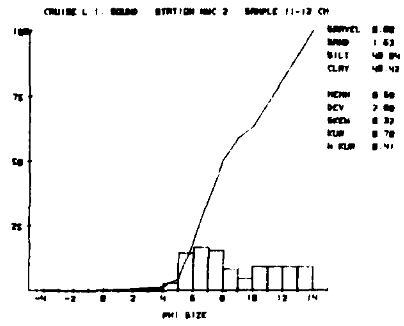
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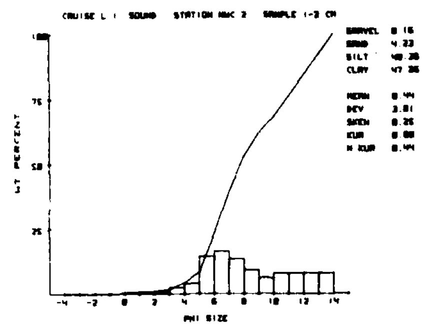
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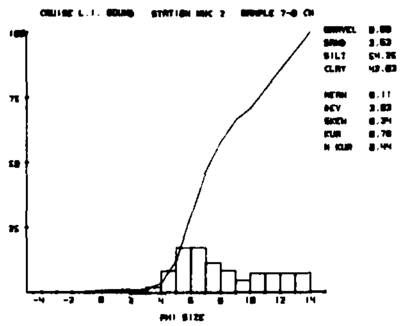
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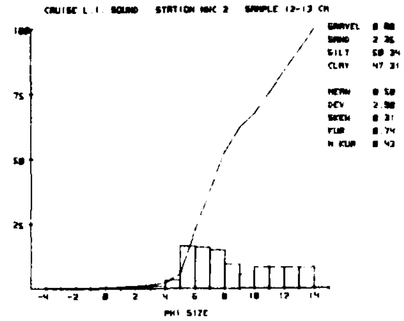
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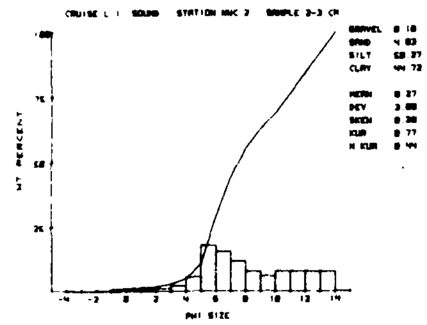
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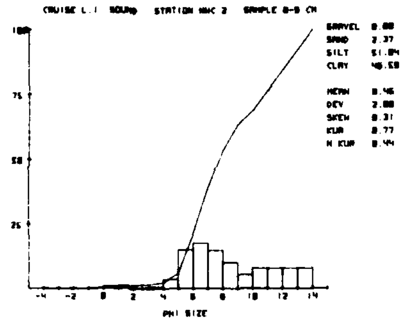
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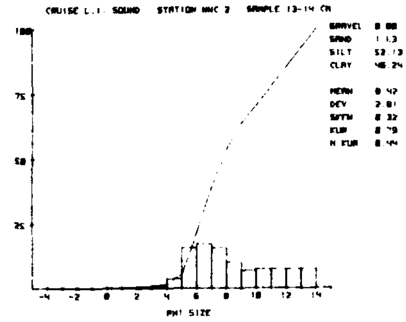
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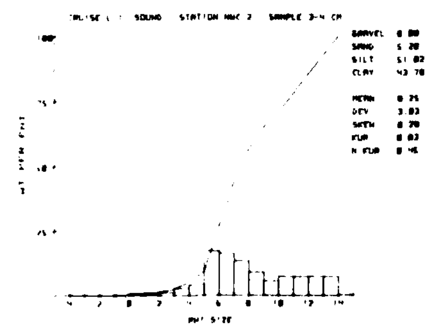
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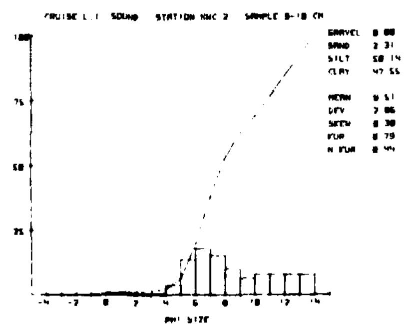
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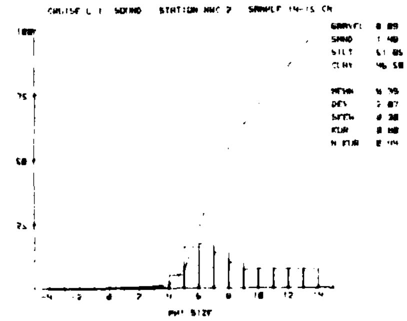
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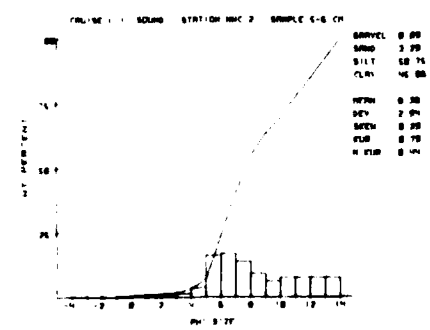
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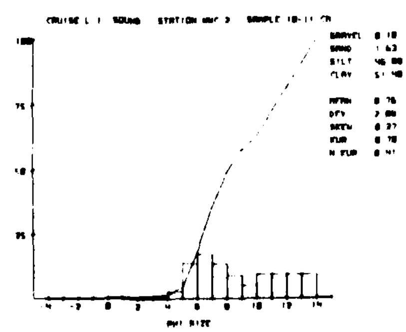
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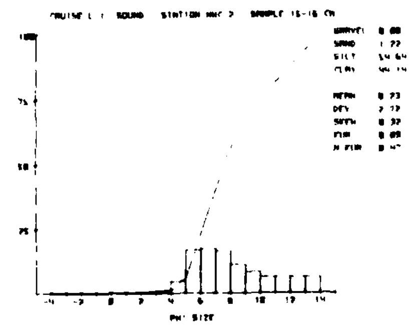
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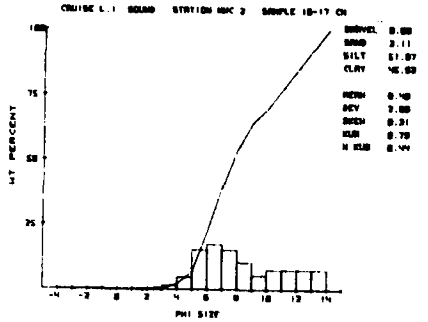
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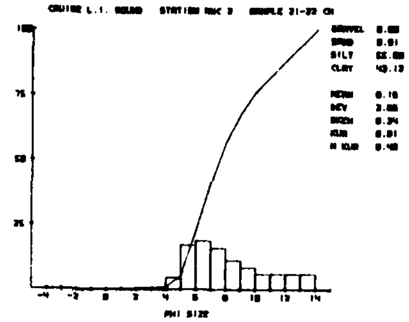
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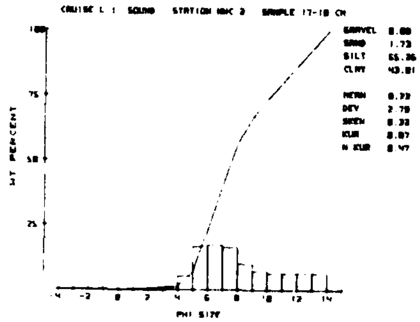
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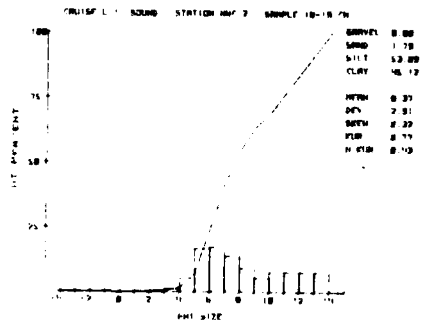
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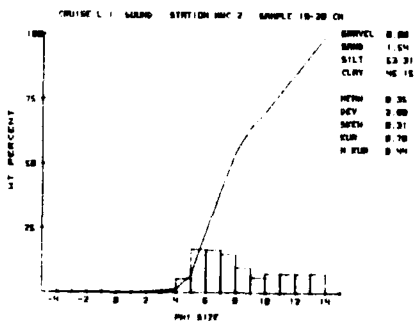
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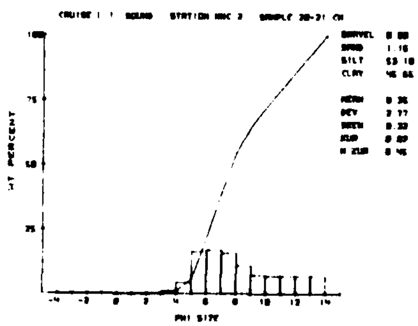
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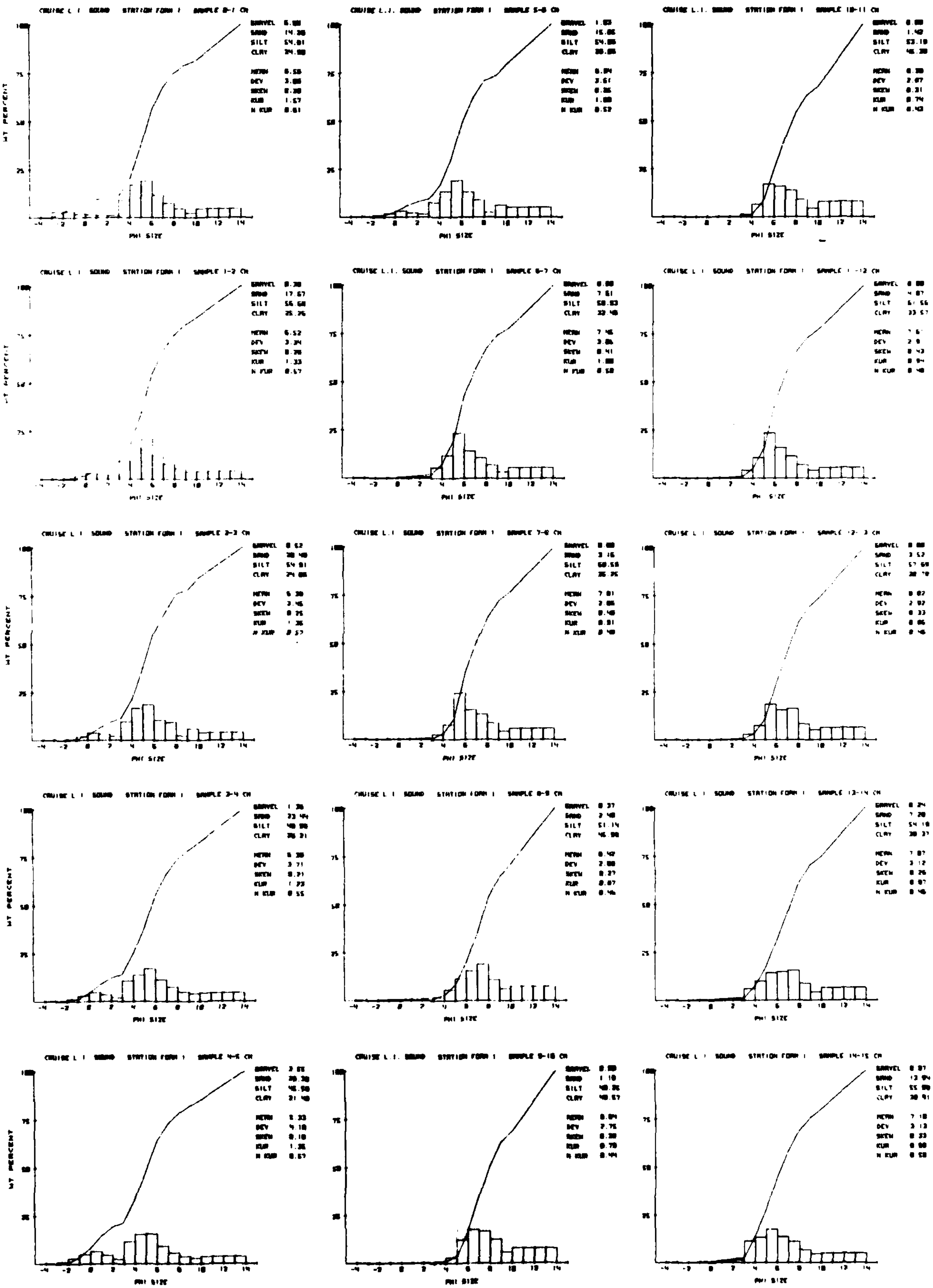
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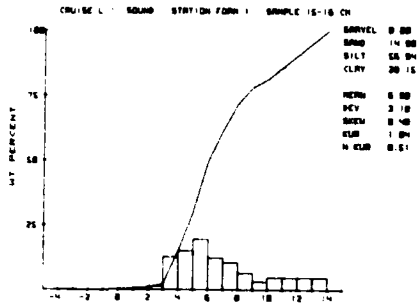
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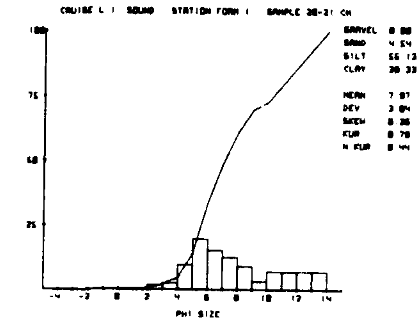
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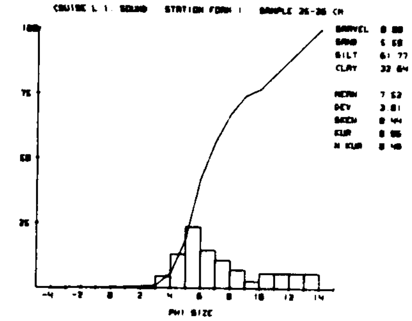
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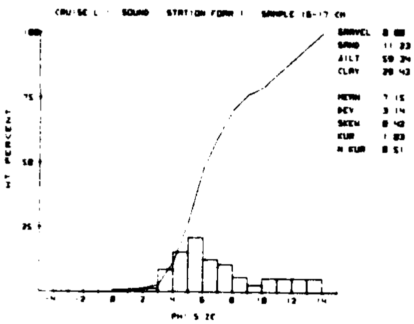
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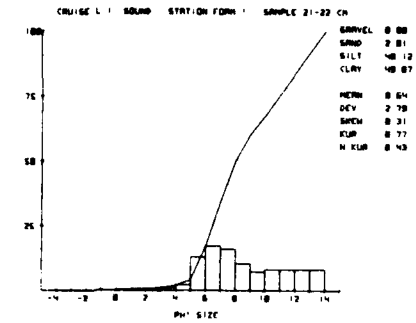
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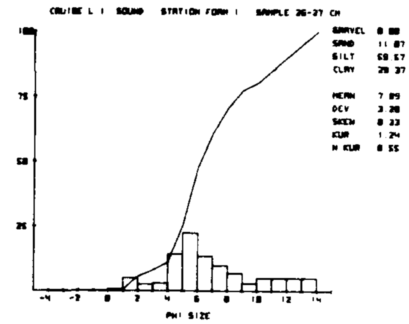
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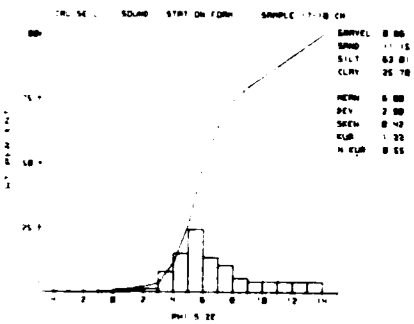
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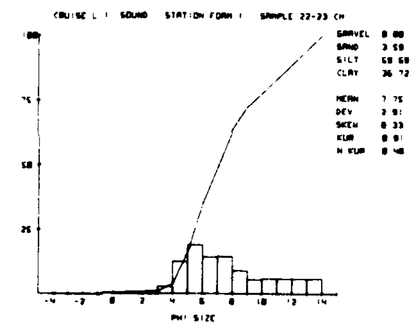
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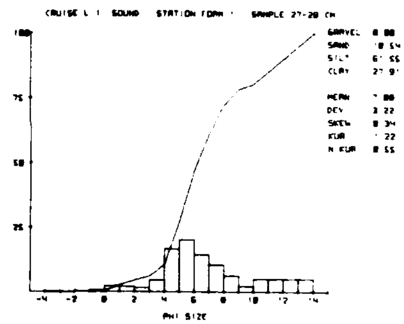
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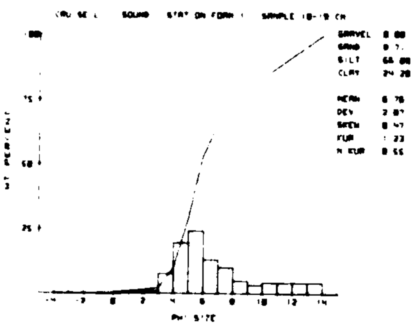
SAMPLE 18-19 CM
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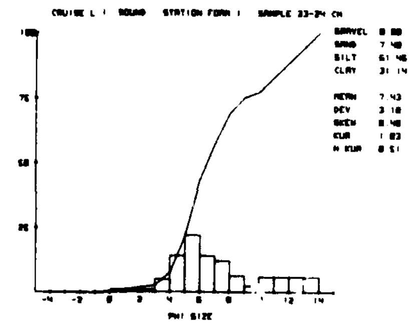
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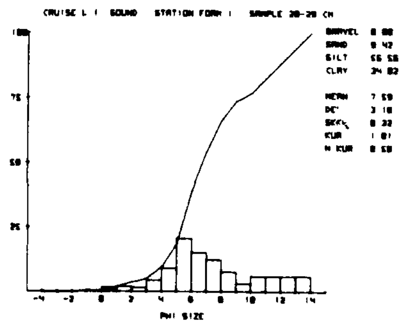
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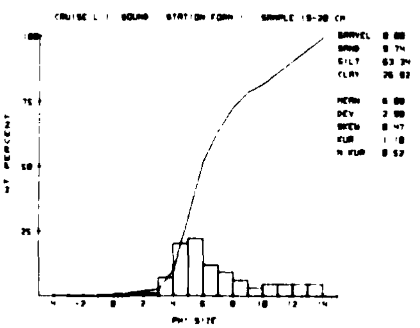
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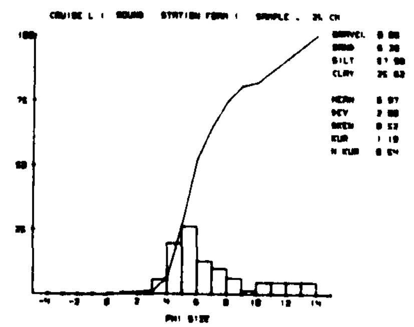
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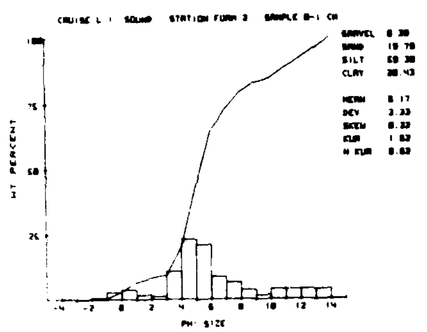
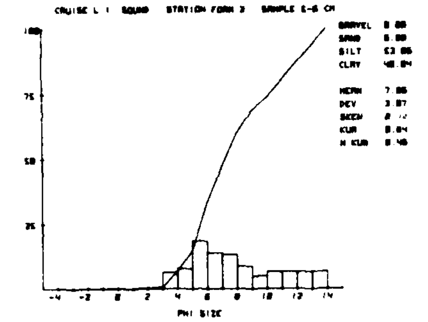
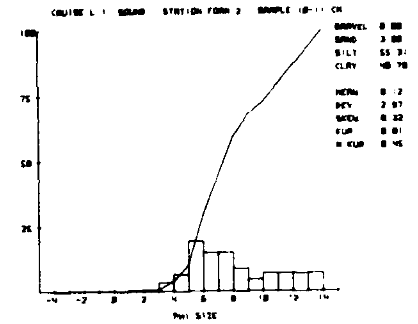
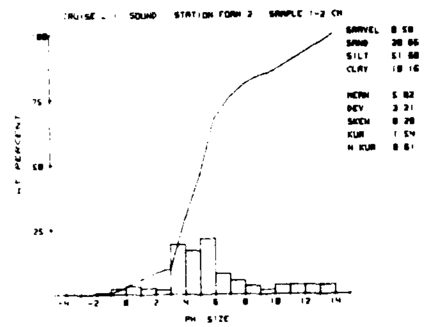
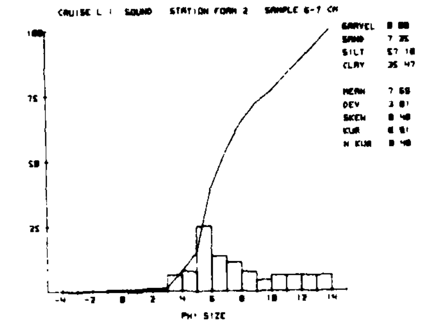
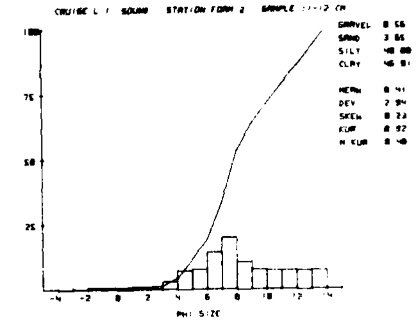
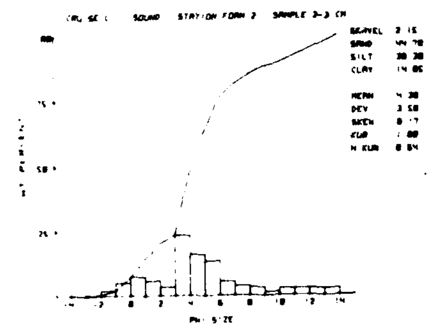
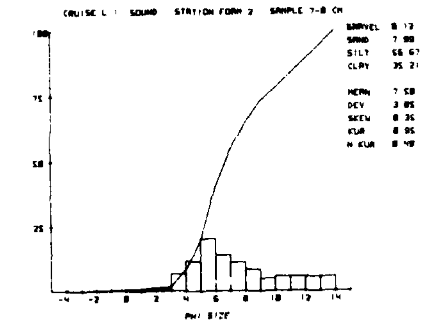
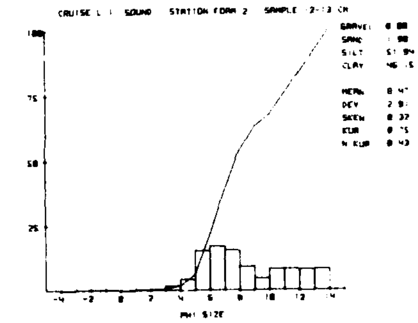
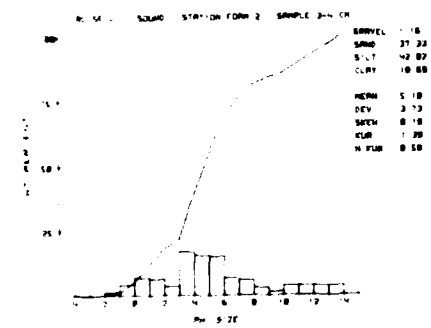
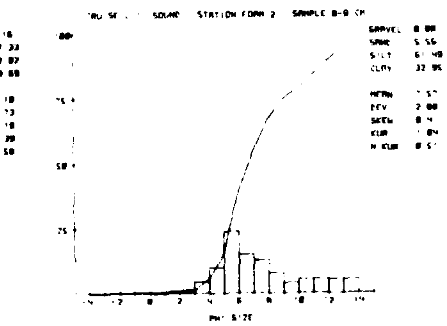
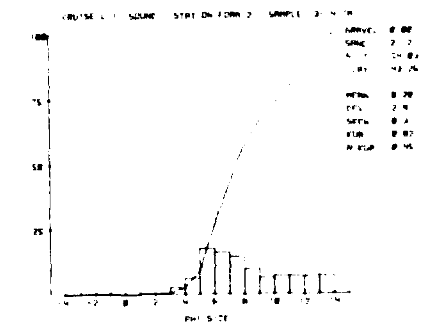
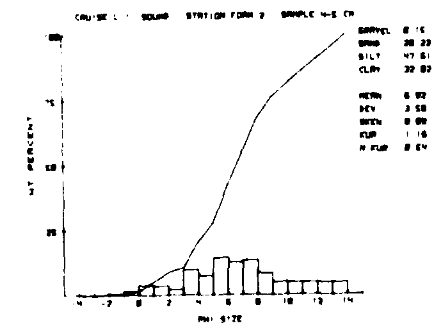
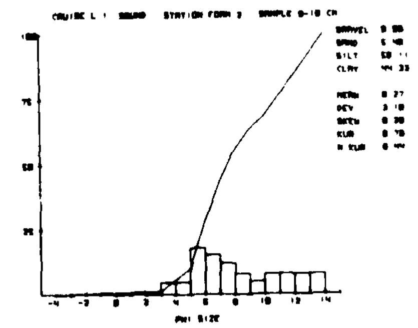
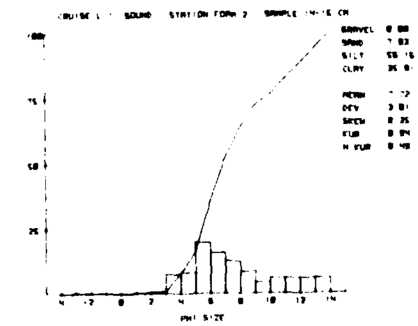

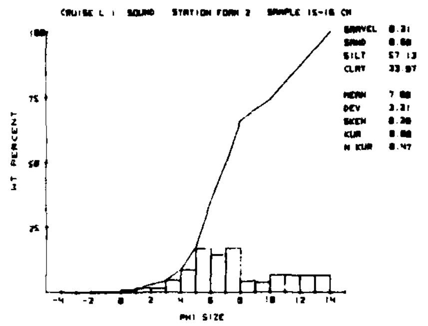
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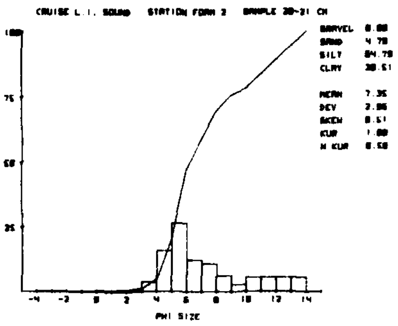
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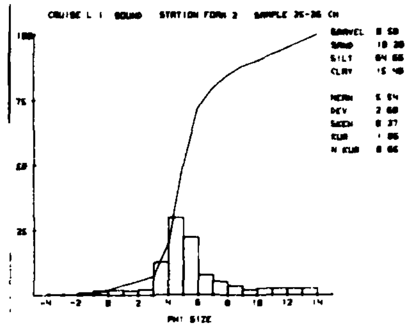
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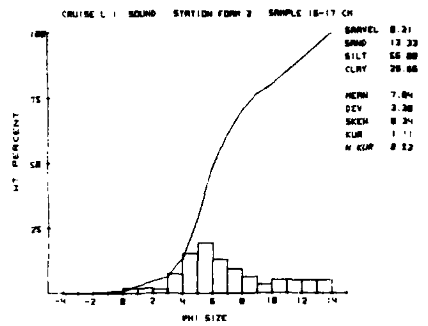
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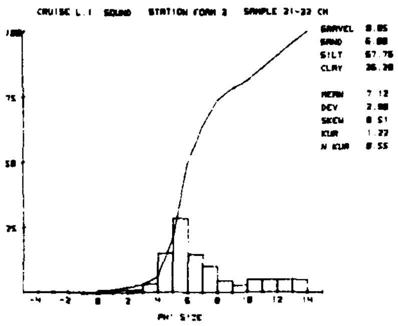
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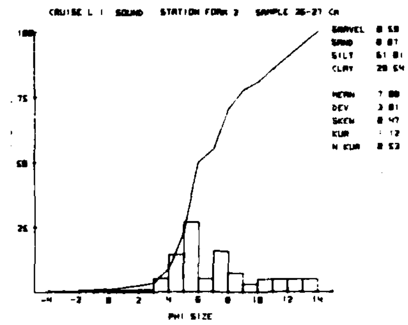
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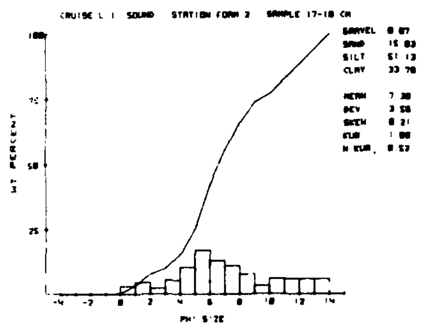
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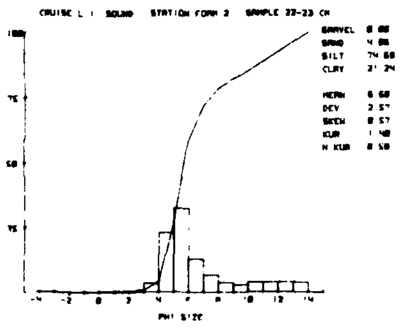
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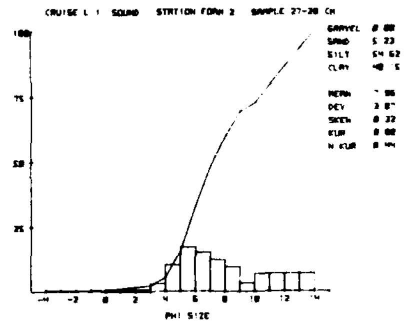
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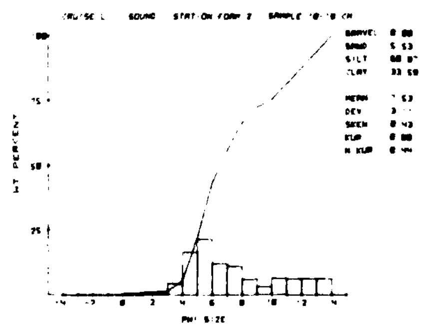
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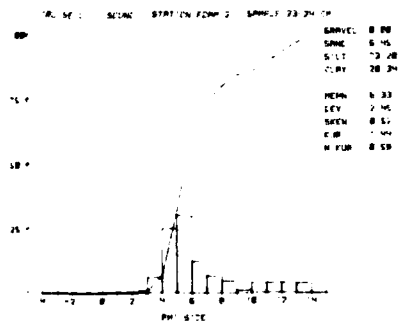
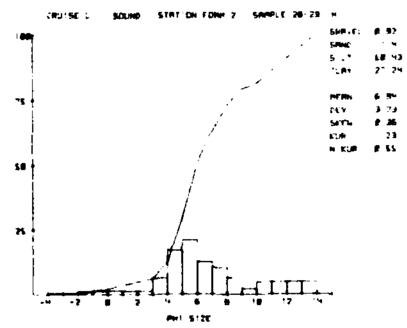
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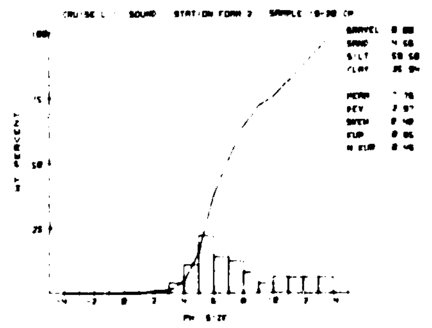
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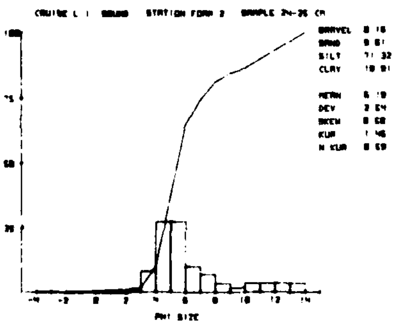
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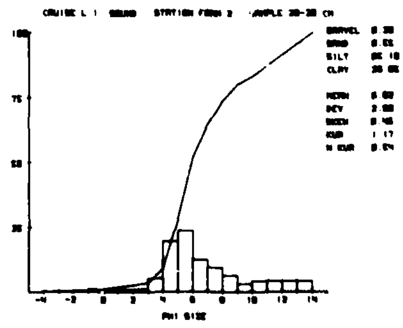
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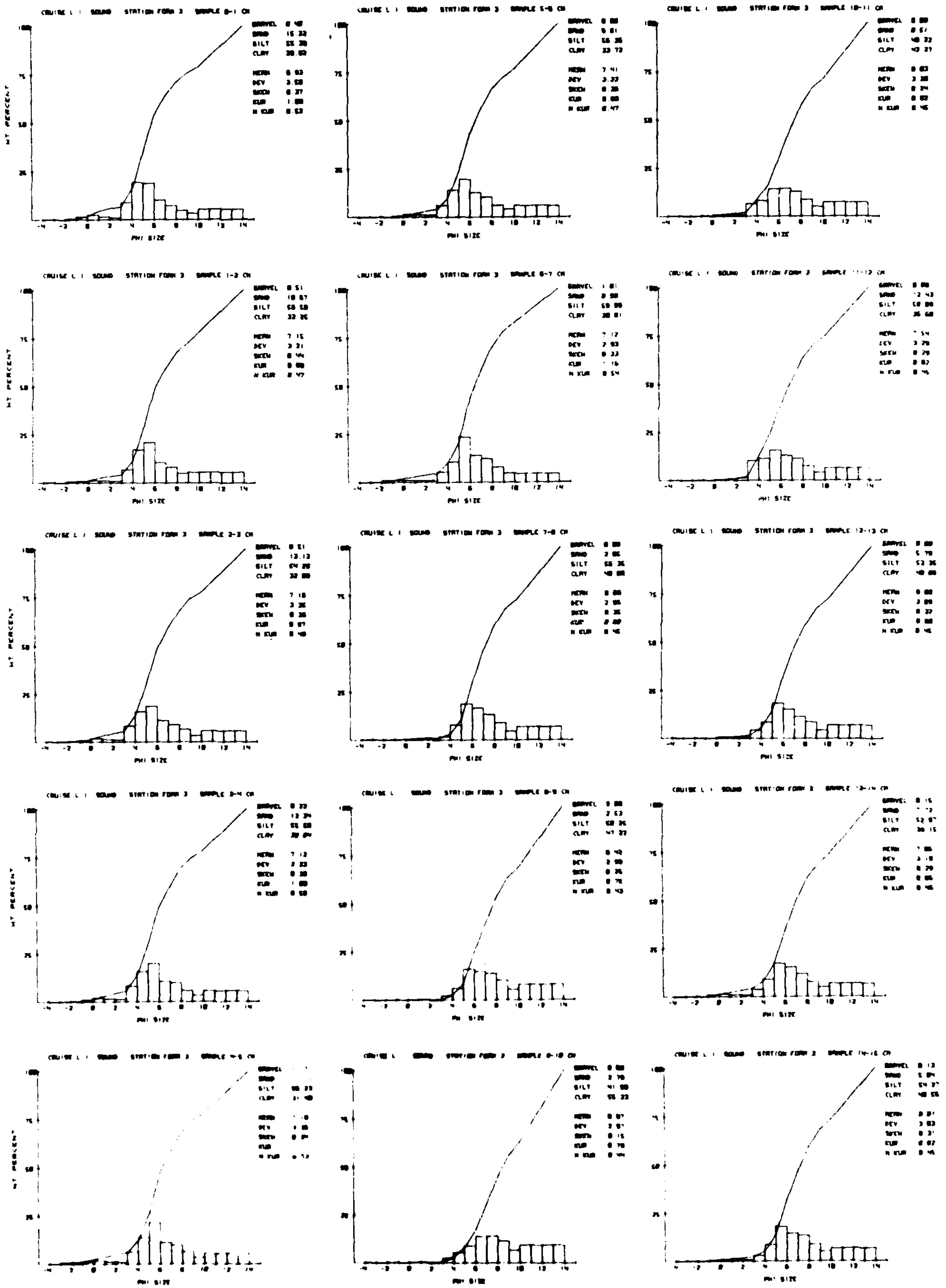

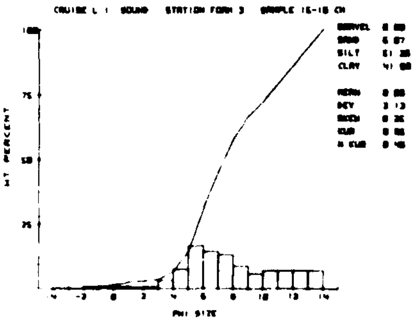
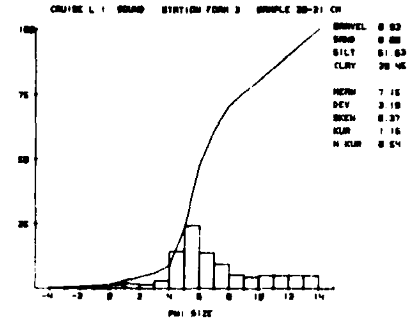
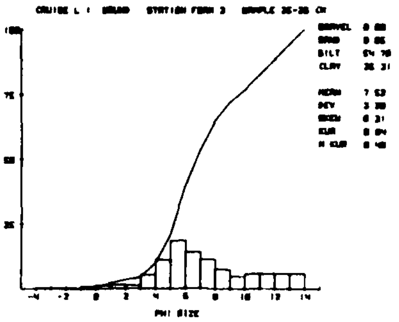
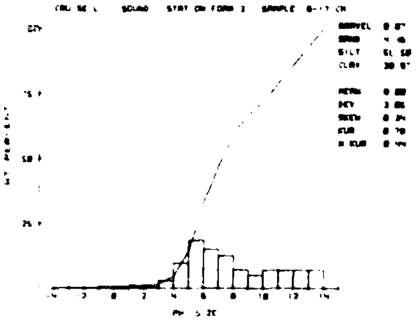
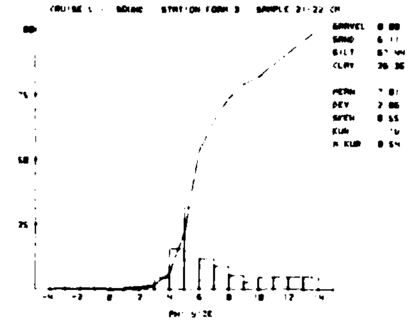
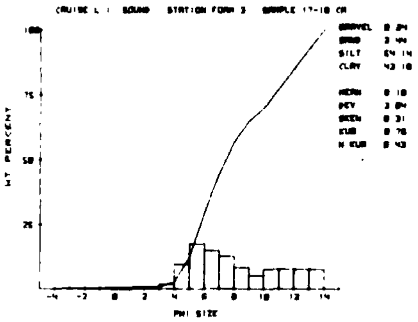
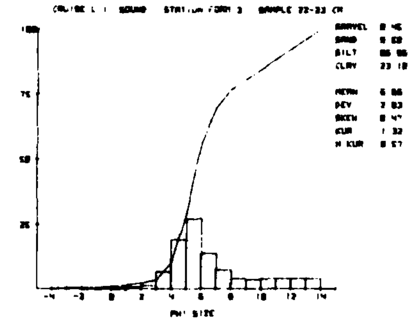
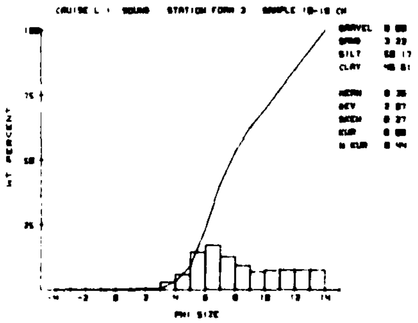
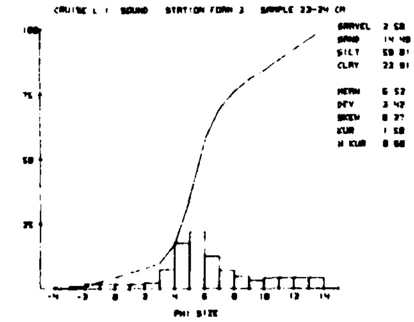
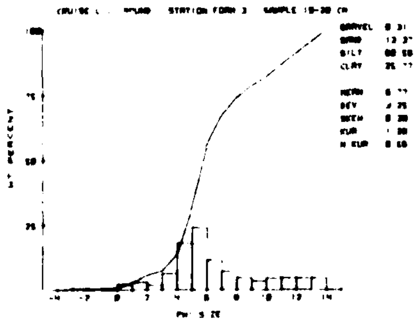
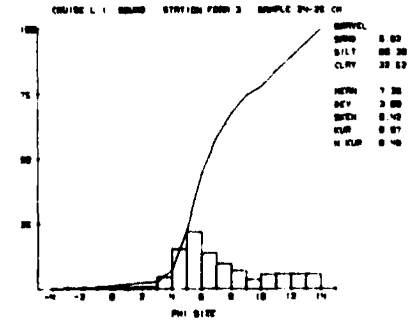

## APPENDIX B.

## POROSITY DATA FOR CORES

## COLLECTED AT FOAM AND NWC SITES

Porosity values (%) for sediments collected with box cores and cylindrical cores (5.8 cm inside diameter) from NWC and FOAM sites, August 27-28, 1980.

Table B-1. Box Core Samples

| Depth (cm) | NWC | | | FOAM | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 |
| 0-1 | 85.1 | 84.2 | 83.1 | 79.7 | 80.7 | 67.9 |
| 1-2 | 78.9 | 79.9 | 77.6 | 79.6 | 77.5 | 67.3 |
| 2-3 | 79.1 | 80.2 | 79.7 | 78.7 | 77.0 | 63.9 |
| 3-4 | 78.7 | 79.9 | 77.6 | 78.0 | 79.4 | 62.9 |
| 4-5 | 76.5 | 80.1 | 76.4 | 78.7 | 79.7 | 67.4 |
| 5-6 | 76.2 | 78.8 | 76.3 | 77.4 | 77.8 | 70.9 |
| 6-7 | 77.0 | 79.7 | 75.0 | 72.4 | 72.1 | 79.9 |
| 7-8 | 76.4 | | 75.6 | 74.8 | 69.6 | 81.3 |
| 8-9 | 75.1 | | 77.4 | 71.9 | 66.4 | 77.4 |
| 9-10 | 76.9 | | 79.2 | 70.9 | 70.6 | 72.8 |
| 10-11 | | | 78.1 | 74.3 | 69.9 | 74.8 |
| 11-12 | | | | | | |

Table B-2. Cylindrical Core Samples

| Depth (cm) | NWC | | | FOAM | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 |
| 0-1 | 81.0 | 78.1 | 78.9 | 69.8 | 69.3 | 71.9 |
| 1-2 | 74.8 | 77.4 | 76.7 | 72.7 | 64.3 | 73.2 |
| 2-3 | 75.5 | 77.3 | 76.8 | 70.8 | 62.2 | 72.7 |
| 3-4 | 75.0 | 77.2 | 76.6 | 69.1 | 59.2 | 72.9 |
| 4-5 | 76.9 | 76.4 | 76.5 | 66.3 | 70.9 | 71.7 |
| 5-6 | 76.6 | 75.9 | 76.7 | 68.3 | 80.6 | 72.8 |
| 6-7 | 76.9 | 76.0 | 77.0 | 70.0 | 77.1 | 73.5 |
| 7-8 | 76.5 | 76.1 | 76.7 | 76.2 | 74.1 | 78.0 |
| 8-9 | 78.0 | 76.9 | 76.0 | 81.7 | 70.8 | 81.9 |
| 9-10 | 77.8 | 76.6 | 77.3 | 82.7 | 77.1 | 81.3 |
| 10-11 | 78.2 | 75.8 | 79.3 | 80.1 | 78.3 | 76.8 |
| 11-12 | 78.9 | 76.2 | 77.1 | 76.5 | 83.5 | 75.0 |
| 12-13 | 78.9 | 77.9 | 77.2 | 80.0 | 78.4 | 77.7 |
| 13-14 | 78.9 | 78.9 | 78.4 | 77.4 | 78.8 | 77.6 |
| 14-15 | 78.7 | 78.6 | 77.7 | 72.4 | 76.8 | 78.7 |
| 15-16 | 78.1 | 78.9 | 76.9 | 71.7 | 80.6 | 76.6 |
| 16-17 | 78.7 | 78.9 | 76.6 | 74.0 | 74.6 | 72.9 |
| 17-18 | 78.4 | 77.1 | 76.1 | 76.2 | 74.2 | 76.8 |
| 18-19 | 77.3 | 77.0 | -- | 67.8 | 76.0 | 79.5 |
| 19-20 | 75.9 | 76.9 | -- | 68.1 | 77.4 | 71.5 |
| 20-21 | 75.6 | 76.5 | -- | 73.2 | 73.8 | 68.3 |
| 21-22 | 75.7 | 75.5 | -- | 76.2 | 69.3 | 67.1 |
| 22-23 | | | | 76.1 | 68.1 | 64.7 |
| 23-24 | | | | 69.6 | 68.3 | 64.8 |
| 24-25 | | | | 67.7 | 62.5 | 70.7 |
| 25-26 | | | | 69.6 | 57.8 | 68.4 |
| 26-27 | | | | 68.3 | 68.4 | -- |
| 27-28 | | | | 69.6 | 73.5 | -- |
| 28-29 | | | | 65.2 | 67.1 | -- |
| 29-30 | | | | | | |

## APPENDIX C.

## COMPRESSIONAL WAVE VELOCITY DATA

## FOR CORES COLLECTED AT FOAM AND NWS SITES

Compressional wave velocity values (m/sec) for sediments collected with cylindrical core (5.8 cm inside diameter) and box cores from NWC and FOAM sites, August 27-28, 1980. All values corrected to 20°C, 30°/oo, 1 atm.

Table C-1. Cylindrical Cores

| Depth (cm) | FOAM SITE | | | NWC SITE | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 |
| 0 | 1486* | 1502* | 1503* | 1484* | 1501* | 1489* |
| 0.5 | 1485 | 1495 | 1497 | 1475 | 1495 | 1471 |
| 1.0 | 1505 | 1508 | 1492 | 1489 | 1484 | 1476 |
| 1.5 | 1508 | 1502 | 1507 | 1491 | 1481 | 1481 |
| 2.0 | 1490 | 1484 | 1472 | 1485 | 1478 | 1479 |
| 2.5 | 1484 | 1483 | 1494 | 1485 | 1478 | 1475 |
| 3.0 | 1486 | 1493 | 1497 | 1477 | 1480 | 1472 |
| 3.5 | 1483 | 1484 | 1479 | 1484 | 1476 | 1472 |
| 4.0 | 1474 | 1476 | 1483 | 1484 | 1474 | 1474 |
| 4.5 | 1476 | 1475 | 1488 | 1480 | 1469 | 1473 |
| 5.0 | 1487 | 1479 | 1483 | 1480 | 1481 | 1465 |
| 5.5 | 1482 | 1479 | 1486 | 1487 | 1485 | 1465 |
| 6.0 | 1463 | 1473 | 1483 | 1487 | 1474 | 1465 |
| 6.5 | 1457 | 1473 | 1482 | 1477 | 1472 | 1465 |
| 7.0 | 1444 | 1477 | 1485 | 1473 | 1481 | 1471 |
| 7.5 | 1477 | 1473 | 1483 | 1469 | 1491 | 1472 |
| 8.0 | 1483 | 1468 | 1485 | 1471 | 1481 | 1467 |
| 8.5 | 1487 | 1470 | 1484 | 1472 | 1471 | 1467 |
| 9.0 | 1481 | 1471 | 1486 | 1473 | 1481 | 1472 |
| 9.5 | 1478 | 1475 | 1485 | 1468 | 1480 | 1474 |
| 10.0 | 1478 | 1474 | 1483 | 1477 | 1480 | 1479 |
| 10.5 | 1477 | 1467 | 1481 | 1472 | 1479 | 1474 |
| 11.0 | 1475 | 1466 | 1483 | 1472 | 1471 | 1473 |
| 11.5 | 1482 | 1466 | 1486 | 1474 | 1478 | 1469 |
| 12.0 | 1489 | 1466 | 1481 | 1477 | 1478 | 1470 |
| 12.5 | 1489 | 1464 | 1481 | 1483 | 1486 | 1474 |
| 13.0 | 1486 | 1466 | 1491 | -- | 1471 | 1476 |
| 13.5 | 1488 | 1473 | 1486 | -- | -- | -- |
| 14.0 | 1486 | 1477 | 1486 | -- | -- | -- |
| 14.5 | 1484 | -- | -- | -- | -- | -- |

* Compressional wave velocities at the sediment-water interface are not sediment velocities.

Table C-2. NWC Box Cores

| Depth (cm) | 1-1 | 1-2 | 2-1 | 2-2 | 3-1 | 3-2 |
|---|---|---|---|---|---|---|
| 0 | 1486* | 1502* | 1503* | 1484* | 1501* | 1489* |
| 0.5 | 1485 | 1495 | 1497 | 1475 | 1495 | 1471 |
| 1.0 | 1505 | 1508 | 1492 | 1489 | 1484 | 1476 |
| 1.5 | 1508 | 1502 | 1507 | 1491 | 1481 | 1481 |
| 2.0 | 1490 | 1484 | 1472 | 1485 | 1478 | 1479 |
| 2.5 | 1484 | 1483 | 1494 | 1485 | 1478 | 1475 |
| 3.0 | 1486 | 1493 | 1497 | 1477 | 1480 | 1472 |
| 3.5 | 1483 | 1484 | 1479 | 1484 | 1476 | 1472 |
| 4.0 | 1474 | 1476 | 1483 | 1484 | 1474 | 1474 |
| 4.5 | 1476 | 1475 | 1488 | 1480 | 1469 | 1473 |
| 5.0 | 1487 | 1479 | 1483 | 1480 | 1481 | 1465 |
| 5.5 | 1482 | 1479 | 1486 | 1487 | 1485 | 1465 |
| 6.0 | 1463 | 1473 | 1483 | 1487 | 1474 | 1465 |
| 6.5 | 1457 | 1473 | 1482 | 1477 | 1472 | 1465 |
| 7.0 | 1444 | 1477 | 1485 | 1473 | 1481 | 1471 |
| 7.5 | 1477 | 1473 | 1483 | 1469 | 1491 | 1472 |
| 8.0 | 1483 | 1468 | 1485 | 1471 | 1481 | 1467 |
| 8.5 | 1487 | 1470 | 1484 | 1472 | 1471 | 1467 |
| 9.0 | 1481 | 1471 | 1486 | 1473 | 1481 | 1472 |
| 9.5 | 1478 | 1475 | 1485 | 1468 | 1480 | 1474 |
| 10.0 | 1478 | 1474 | 1483 | 1477 | 1480 | 1479 |
| 10.5 | 1477 | 1467 | 1481 | 1472 | 1479 | 1474 |
| 11.0 | 1475 | 1466 | 1483 | 1472 | 1471 | 1473 |
| 11.5 | 1482 | 1466 | 1486 | 1474 | 1478 | 1469 |
| 12.0 | 1489 | 1466 | 1481 | 1477 | 1478 | 1470 |
| 12.5 | 1489 | 1464 | 1481 | 1483 | 1486 | 1474 |
| 13.0 | 1486 | 146 | 1491 | -- | 1471 | 1476 |
| 13.5 | 1488 | 1473 | 1486 | -- | -- | -- |
| 14.0 | 1486 | 1477 | 1486 | -- | -- | -- |
| 14.5 | 1484 | -- | -- | -- | -- | -- |

* Compressional wave velocities at the sediment-water interface are not sediment velocities.

Table C-3. Foam Box Cores

| Depth (cm) | 1-1 | 1-2 | 1-3 | 2-1 | 2-2 | 3-1 | 3-2 |
|---|---|---|---|---|---|---|---|
| 0 | 1493* | 1497* | 1493* | 1517* | 1491* | 1516* | 1519* |
| 0.5 | 1494 | 1499 | 1493 | 1526 | 1486 | 1525 | 1504 |
| 1.0 | 1502 | 1489 | 1489 | 1513 | 1492 | 1524 | 1519 |
| 1.5 | 1495 | 1491 | 1478 | 1498 | 1492 | 1523 | 1513 |
| 2.0 | 1489 | 1487 | 1483 | 1498 | 1499 | 1524 | 1504 |
| 2.5 | 1480 | 1480 | 1488 | 1496 | 1480 | 1509 | 1495 |
| 3.0 | 1484 | 1475 | 1492 | 1483 | 1487 | 1513 | 1511 |
| 3.5 | 1484 | 1475 | 1484 | 1487 | 1480 | 1502 | 1519 |
| 4.0 | 1480 | 1481 | 1483 | 1477 | 1480 | 1502 | 1504 |
| 4.5 | 1477 | 1481 | 1484 | 1485 | 1485 | 1500 | 1503 |
| 5.0 | 1478 | 1471 | 1484 | 1484 | 1477 | 1500 | 1505 |
| 5.5 | 1479 | 1477 | 1480 | 1472 | 1477 | 1497 | 1499 |
| 6.0 | 1478 | 1480 | 1476 | 1481 | 1477 | 1506 | 1494 |
| 6.5 | 1478 | 1475 | 1479 | 1484 | 1477 | 1508 | 1480 |
| 7.0 | 1484 | 1473 | 1488 | 1484 | 1482 | 1501 | 1469 |
| 7.5 | 1480 | 1473 | 1485 | 1481 | 1485 | 1494 | 1479 |
| 8.0 | 1475 | 1482 | 1482 | 1489 | 1483 | 1489 | 1469 |
| 8.5 | 1483 | 1475 | 1486 | 1494 | 1486 | 1494 | 1465 |
| 9.0 | 1486 | 1467 | 1479 | 1486 | 1486 | 1491 | 1464 |
| 9.5 | 1482 | 1479 | 1470 | 1497 | 1489 | 1471 | 1465 |
| 10.0 | 1486 | 1499 | 1473 | 1516 | 1490 | 1475 | 1479 |
| 10.5 | 1504 | 1499 | 1479 | 1509 | 1490 | 1475 | 1488 |
| 11.0 | 1526 | 1493 | 1473 | 1508 | 1496 | 1478 | 1477 |
| 11.5 | 1524 | 1493 | 1476 | 1522 | 1519 | 1494 | 1476 |
| 12.0 | 1513 | 1509 | 1481 | 1530 | 1516 | 1489 | 1474 |
| 12.5 | 1512 | 1511 | 1498 | 1531 | 1504 | 1508 | 1474 |
| 13.0 | 1507 | 1516 | 1488 | 1532 | 1492 | 1515 | 1475 |
| 13.5 | 1496 | 1498 | 1484 | 1510 | 1492 | 1505 | 1463 |
| 14.0 | 1494 | 1489 | 1479 | 1499 | 1492 | 1494 | 1483 |
| 14.5 | 1493 | 1491 | 1477 | -- | 1508 | 1480 | -- |
| 15.0 | -- | 1491 | 1484 | -- | 1513 | -- | -- |
| 15.5 | -- | 1491 | 1484 | -- | 1500 | -- | -- |
| 16.0 | -- | -- | 1462 | -- | 1498 | -- | -- |

* Compressional wave velocities at the sediment-water interface are not sediment velocities.

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Sediment Geoacoustic Models

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Concurrent acoustical, physical, and biological properties were measured from three replicate core liner and three replicate box core samples collected by scuba divers from each of two locations in Long Island Sound 27-28 August 1980. Grain size distribution, porosity, and compressional wave velocity measurements were taken at 1 cm intervals in the core liner samples. Compressional wave velocities were measured at 0.5 cm intervals and porosity values at 1.0 cm intervals in the box core samples. X-radiographs were made of sediments collected with the box cores.

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A very low diversity pioneering assemblage dominated by the filter-feeding bivalve Mulinia lateralis was found at the shallower (10 m water depth) FOAM site. Nearby sediments were dominated by pioneering, surface tube-dwelling polychaetes and amphipods. Sediment laminations produced by storm-induced erosional and depositional events were preserved at the FOAM site because sediment mixing by macrofauna was uncommon below the upper few centimeters of sediment. Horizontal patchiness of macrofauna and preservation of sediment laminations resulted in vertical and horizontal variability in sediment physical and acoustical properties. Spatial and temporal changes in dominant species at the FOAM site resulted in considerable large scale (10 to 100 meters) variability in surface physical and acoustical properties.

A low diversity equilibrium assemblage dominated by surface deposit-feeding bivalves and deeper dwelling errant and tube-dwelling polychaetes was found at the deeper (16 m water depth) NWC site. Intense bioturbation by surface deposit-feeding bivalves precluded preservation of the primary laminations which had been created by storm-induced erosional and depositional events. Bioturbation was responsible for the spatial and temporal homogeneity of physical and acoustical properties at the NWC site. Deeper dwelling polychaetes mixed the sediment to depths of 15 cm, creating random variability of fine-scale physical and acoustical structure by production of burrows, tubes, and feeding voids, and by mixing shell remains throughout the upper 15 cm.

The physical and acoustical properties of coastal marine sediments are controlled by the interaction of biological and hydrodynamic processes. Study of the relationships between these two processes and the resultant sedimentary properties should lead to increased understanding and improved geoacoustic predictive models of coastal environments.

It is obvious from these data that caution must be exercised when sediment acoustic properties are predicted from sediment physical properties for shallow-water coastal sediments. Sampling designs which either define small-scale sediment property variability or make measurements over long pathlengths must be used to predict shallow-water sediment acoustic properties.

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